RESPONSE IN MATERNAL TRAITS TO SELECTION FOR GROWTH AND FEED EFFICIENCY IN SWINE

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ABSTRACT

The objective of this study was to determine the relationship between the traits of average daily gain, backfat, loin muscle depth, feed intake and feed conversion measured in growing gilts and their subsequent feed intake (as estimated by feed delivery) in lactation, and to estimate the effects of lactation feed intake on subsequent maternal productivity and sow longevity. Phenotypic performance measurements and estimated breeding values (EBV) were compared with first and second parity lactation feed delivery in a group of selected nucleus gilts of 3 genetic lines. The effects of lactation feed delivery on weaning to conception interval, total piglets born in the subsequent litter and lifetime productivity measures were investigated. Genetic parameters for the growing period traits of average daily gain, backfat, loin muscle depth, daily feed intake and feed conversion, as well as maternal productivity traits of litter size (number alive at day 2), weaning to conception interval and litter weaning weight were estimated and EBV were computed.

Phenotypes of growth rate, feed intake, backfat and loin muscle depth recorded in the growing period were not good predictors of lactation feed delivery. However, one genetic line (YO-A) showed significant correlations between second parity lactation feed delivery and growth rate and loin muscle depth measured in the growing period.

EBV calculated for the growing period traits of growth rate, feed intake and feed conversion showed much stronger relationships with lactation feed delivery than the growing period phenotypes, particularly for parity 2. Parity 2 lactation feed delivery showed favorable correlations with EBV for growth rate and feed conversion and an unfavorable correlation with the growing period daily feed intake EBV.

Lactation feed delivery in the first and second parity had significant effects on the odds of occurrence of the next litter, next litter total born, stayability to parity 3 or parity 4 and sow longevity. Since lactation feed intake is very important to subsequent productivity and longevity of sows and has a positive (unfavorable) genetic correlation

with growth period feed intake, it is recommended that lactation feed intake be measured directly and included in the selection goal.

The correlation between lactation feed delivery in parity 1 and parity 2 was low at 0.28 across genetic lines, leading to the conclusion that lactation feed delivery in the first and second parities appear to be different traits under different control mechanisms.

It is concluded that a balanced selection program for maternal lines that includes selection for reduced feed intake, feed conversion or residual feed intake measured in the growing period, should also include selection for increased lactation feed intake (probably in combination with changes in sow body weight or backfat during lactation in order to prevent negative consequences for sow longevity or productivity). It is also recommended that lactation feed intake in the first and later parities be evaluated as separate traits.

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LIST OF ABBREVIATIONS

ADG	Average daily gain
BLUP	Best linear unbiased prediction
CCSI	Canadian Center for Swine Improvement
EBV	Estimated breeding value
F1	First filial generation
FIRE	Feed intake recording equipment
INRA	National Institute for Agricultural Research (France)
LFI	Lactation feed intake
NE	Net energy
PD_{max}	Point of maximum protein deposition
RFID	Radio frequency identification
WCI	Weaning to conception interval

1. INTRODUCTION

In the past 20 years, swine genetic companies have made substantial progress in increasing maternal productivity. Many maternal lines have gained two or more pigs per litter in live born piglets. At the same time, selection for reduced backfat that began in earnest in the early 1970's has continued, with a further reduction of three to four mm of backfat at 100 kg obtained since 1990.

Selection for improved feed conversion and reduced backfat may have reduced appetite in modern genetic lines, and continued selection for growth rate has resulted in a larger mature body size and a higher ratio of muscle to fat, both associated with higher maintenance requirements. In comparison to the sow of 20 years ago, the modern prolific sow is being asked to raise a substantially larger litter, has higher body maintenance requirements, and in the case of young sows, continued growth, all with a lower voluntary feed intake and reduced body reserves of backfat.

Current selection programs for pigs may be setting up a scenario whereby the young sow is unable to consume enough feed to support her litter and her own growth, has limited backfat reserves to draw upon, and is at risk of premature culling due to an inability to re-breed, reduced numbers born in the second and third parities or leg weakness issues resulting from poor body condition. Sow culling and removal rates are already a serious production problem and it is of concern that intensive selection for feed conversion may reduce appetite and further exacerbate problems with retention of young sows in the herd.

This research explored the relationships between the production traits of feed intake, feed conversion, growth rate, backfat and loin muscle depth measured in the post weaning growth phase in gilts and lactation feed intake and subsequent reproductive performance of the sow. Data was collected in a genetic nucleus herd containing three genetic lines. Phenotypes for growth rate, backfat and loin muscle depth in the growing pig were measured at an off-test age of approximately 150 days. Post selection, a 17 day measure of individual feed intake was obtained. Genetic parameters for growth period traits of average daily gain (ADG), daily feed intake, feed conversion and ultrasound backfat and loin depth were estimated from the entire breeding company population and estimated breeding values (EBV) were computed. Data on maternal productivity including conception rate, age at first farrowing, litter size, litter weaning weight, weaning to conception interval and longevity were collected. Genetic parameters were estimated and EBV computed for the maternal traits of litter size, litter weaning weight and weaning to conception interval. Relationships between traits of the growing pig, and future sow productivity and longevity traits were explored.

2.0 LITERATURE REVIEW

2.1 Reasons for Sow Removal

A major reason for culling, particularly in young sows is reproductive failure (failure to show estrus or failure to conceive) and this situation has not changed substantially in 30 years, as shown in Table 2.1.

Table 2.1: Reproductive failure as a percentage of total removals.

Author	% of Removals Due to Reproductive Failure
Dagorn and Aumaitre (1979)	31%
Stone (1981)	13%
Friendship et al. (1986)	27%
Engblom et al. (2010)	32%
Hughes et al. (2010)	43%

In a large study of U.S. PigCHAMP records on 104,000 sows, Engblom et al. (2010) noted that 18% of sows were removed after parity 1, and 30% did not successfully reach parity 3, which is when a sow is estimated to recover her gilt acquisition and development costs (Stalder et al. 2003). In the study of Engblom et al. (2010), involuntary removals accounted for 70% of total removals. Over 50% of the removals in parity 1 were due to reproductive failure and reproductive failure was the largest reason for sow removal through parity 5.

Reasons for culling change gradually with increasing parity. Reproductive failure and locomotion problems account for a lower percentage of removals of older sows while farrowing and weaning productivity and voluntary removals such as old age and size account for an increasing percentage of removals (Mote et al. 2008; Engblom 2010). A high rate of removals in early parities affects the profitability of sow operations because older sows have more live born piglets, wean heavier piglets, re-breed more reliably and have a higher salvage value at removal (Mote et al. 2009; Stalder et al. 2003; Engblom et al. 2010). The cost per weaned pig of the breeding gilt is reduced if more parities and weaned piglets are produced per gilt entering the herd (Stalder et al. 2003). In addition, piglets from first parity sows do not have the same immune status as those from older parity sows (Moore 2001).

2.2 The Importance of Feed Intake in Lactation

A lactating sow must meet the energy and protein demands of milk production for her litter and for maintenance (Whittemore 1998). McGlone et al. (2004) showed that sows continue to gain weight up to parity six, so young sows are still using energy and protein for growth. Any deficit between input (feed intake) and output in milk production and maintenance must be made up by mobilization of body fat and protein, the only other possible nutrient source (Ball et al. 1998). As a result, most sows lose weight and backfat during lactation. Noblet and Etienne (1987) determined sow weight loss in lactation to be 648 grams/day during a 21 day lactation and estimated the composition of this weight loss to be 58% muscle and 42% fat.

Many experiments have looked at the effect of energy and protein deficits during lactation on the subsequent reproductive performance and lifetime productivity of the sow. Most have found extended weaning to estrus and weaning to conception intervals in sows with reduced lactation feed intake (Anil et al. 2006; Young et al. 1991; Eissen et al. 2003; Koketsu and Dial 1996). Some have also found a lower pregnancy rate (Baidoo et al. 1992) and a smaller subsequent litter size (Eissen et al. 2003; Koketsu and Dial 1996). Anil et al. (2006) found that the odds of removal prior to the next parity decreased by 30% for each 1 kg increase in daily feed intake in lactation. Eissen et al. (2003) found that sows with lower body weight loss in their first lactation had a larger second litter (+1.28 piglets $P<0.01$). Knauer et al. (2010) reported that higher lactation intake, earlier age at first farrowing and at first estrus improved sow stayability to parity 4 in all six genotypes evaluated in the National Pork Producers Council Maternal Line National Genetic Evaluation Program (Knauer et al. 2010).

Some studies have reported that the pattern of feed intake in lactation may be important as well. Anil et al. (2006) reported that sows consuming less than 3.5 kg of feed/day in the first two weeks of lactation had a higher risk of removal prior to their next parity and that a sow that had a complete feed refusal for a single day in the first 14 days of lactation had the highest risk of removal prior to their next parity. Hermesch et al. (2008) reported similar findings in that gilts that consumed less than 3.5 kg feed/day in lactation were 32% (number weaned not fitted) or 17% (number weaned fitted) less likely to stay in the herd for a second parity than the highest intake class of gilts consuming 5.5 kg/day.

Two experiments modeled lactation feed intake as a curvilinear function and measured the effects of deviations from that curve on weaning and re-breeding performance. Yoder et al. (2012) used least square means from a mixed model to predict daily feed intake for each day of a 22 day lactation for purebred Yorkshire, purebred Landrace and F1 crosses between these breeds. First parity sows in both purebred and F1 groups had the lowest average rate of change in intake and the most variation in intake of all parity groups. Overall lactation intake and rate of change of intake were both lowest in the summer months. Sows that had the highest overall daily intake, and the highest rate of change of daily intake weaned the heaviest litters and had shorter wean to first service intervals.

In a similar experiment, Schinckel et al. (2010) calculated a predicted lactation curve using a non-linear mixed model and measured the effects of large differences from the predicted intake. Schinckel defined a transient reduction in feed intake as more than 1.6 times the residual standard deviation (about 3 kg) less than the predicted daily intake for two consecutive days. Parity 1 sows had a higher incidence of transient reductions in early and mid lactation than older sows. In agreement with Yoder et al. (2012), Schinckel et al. (2010) found the lowest overall feed intake during the summer season (in Indiana) but found that variability of intake did not increase in the summer months. Average daily feed intake for Yorkshire and Landrace sows increased with increasing parity up to parity 3 and remained constant from parity 4 to 7. Overall, daily feed energy intake had a linear-quadratic relationship with number weaned and a linear relationship with weaning weight. Sows weaning heavier than average litters consumed only 12 to 14% of the additional energy required for the extra litter weight. Schinckel et al. (2010) recommended that selection programs incorporate measurements of lactation feed intake and body weight loss in the selection goal. Figure 2.1 sows the predicted daily feed intake for Landrace and Yorkshire sows.

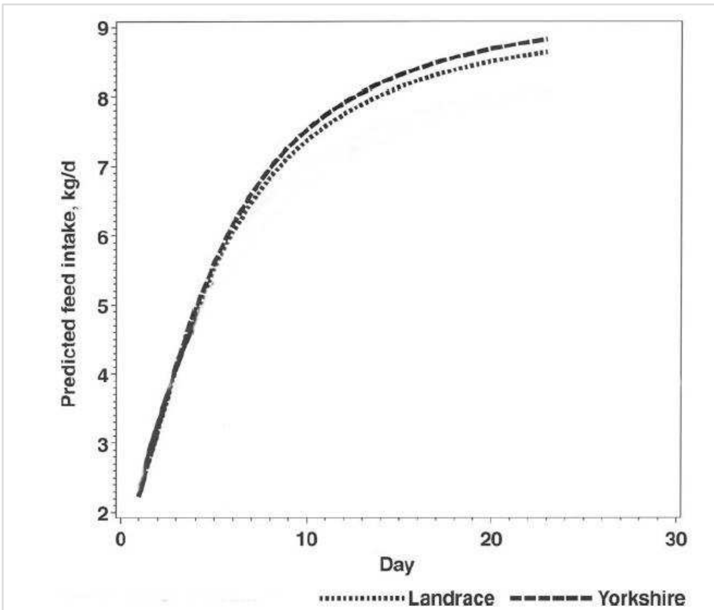

Figure 2.1: Predicted daily feed intake for Landrace and Yorkshire sows. Modified from Schinkel et al. 2010.

Anil et al. (2006) found that the odds of removal prior to the next parity decreased by 17% for each 1 mm increase in backfat at weaning and several studies have reported that backfat at weaning or backfat loss in lactation affects weaning to estrus or weaning to conception intervals or length of productive life. For example, Young et al. (1991) reported an increased risk of culling for sows with weaning backfat thickness of less than 12 mm. Houde et al. (2010) compared two herds with different management strategies for feeding lactating sows and found that, in the herd with the largest backfat losses, live born pigs and pigs alive at 48 hours were reduced and that parity 1 and 2 sows had extended weaning to estrus intervals. Sows in this herd had fewer pigs alive 48 hours after birth in parities 3 and 4 than in their first parity. Houde et al. (2010) recommended a strategy which maintained sow backfat as much as possible through successive parities. Whittemore and Morgan (1990) proposed a curvilinear model for the relationship between backfat at weaning and weaning to estrus interval whereby weaning to estrus interval decreased with increasing backfat at weaning up to an asymptote of about 23 mm, then increased for very fat sows at weaning.

Mellagi et al. (2013) allocated sows in three parity classes to two lactation weight loss classes of <= 1% and > 1% of body weight and observed farrowing rate, weaning to estrus interval and total born in the subsequent parity. Parity 1 and 2 sows in the high weight loss class had reduced subsequent farrowing rate while older sows showed no effect of weight loss on subsequent farrowing rate. Weight loss did not affect weaning to estrus interval in this study but higher weight loss did result in decreased litter size in the next parity.

The various factors affecting sow re-breeding performance and longevity in the herd are not independent of each other. Decreased sow feed intake in lactation results in increased mobilization of body reserves resulting in increased backfat and protein loss. Feed intake in gestation and body condition at parturition both affect lactation intake (Whittemore and Morgan 1990) in that fatter sows at farrowing have lower lactation intake and greater loss of backfat and body weight in lactation. Some controlled studies demonstrating large effects from low energy or protein intake in lactation have involved substantial reductions in energy or protein intake beyond what might be experienced under normal sow management conditions. For example, Clowes et al. (2003) fed three lactation diets that caused sows to lose 7, 9 or 16% of total body protein at parturition and found reduced follicular development at weaning in sows that had lost the most protein mass. Baidoo et al. (1992) restricted lactation intake by 50% (3 kg/d vs. 6 kg/d) and found a longer weaning to estrus interval and a lower percentage of sows showing estrus prior to 10 days post weaning for restricted sows. Hoving et al. (2012) subjected sows to a moderate feed intake restriction in lactation (7 kg maximum intake vs. an average of 8 kg for unrestricted sows) and compared high weight loss and low weight loss sows for reproductive performance in the subsequent breeding. Pregnancy rate was higher for low weight loss sows (96 vs. 75%). High weight loss sows had a lower number of implantation sites (17.2 vs. 19.5), lower embryonic survival (65.6 vs. 77.4%) and lower number of viable embryos (14.9 vs. 16.8) when sows were slaughtered 36 days post insemination.

2.3 Litter Size and Lactation Intake

Sow milk production is stimulated by demand and sows nursing larger litters produce more milk (Auldist et al. 1998). Linear relationships between number of pigs nursed and milk production were reported by Auldist and King (1995), Auldist et al. (1998) and O'Grady et al. (1985). However, this linear increase in milk production is not sufficient to prevent a reduction in piglet growth rate and weaning weight in larger litters which was present in all of the studies above. Parity was also a significant factor in the study of O'Grady et al. (1985). Primiparous sows have a smaller body size and lower feed intake capacity.

In contrast to milk production, lactation feed intake does not show a linear increase with litter size, suggesting that mobilization of body resources will be higher with larger litters. Eissen et al. (2003) compared the daily feed intake of primiparous sows of three genotypes nursing 7 to 14 piglets. One genotype exhibited a significant quadratic effect of litter size with daily feed intake maximized at 10.8 piglets in the nursed litter. A second genotype showed a similar curve but the quadratic effect of litter size was non-significant, while the third genotype showed no linear or quadratic effect of litter size on daily feed intake. Auldist et al. (1998) also reported a tendency for lactation intake to approach a maximum with large litters in the later stages of lactation.

2.4 Feeding the Lactating Sow

Feeding the lactating sow is a constant challenge in pig farm management and management of lactation feeding has been the subject of many research and extension papers (Aherne 2004; Baidoo et al. 1992; Hardy 2003; Vignola 2009). Sows must move from a gestation feeding level of about 2 kg daily to a peak lactation intake of 7 to 8 kg per day as quickly as possible to support their own maintenance and litter gains of 2.5 kg per day or more. For example, a litter of 11 piglets averaging 1.4 kg at birth and weaned at 20 days of age and weighing 6.5 kg/pig represents a litter daily gain of 2.8 kg. Table 2.2 summarizes the energy and feed requirements of lactating sows based on a feed energy density of 13.6 MJ ME/kg (3250 kcal ME/kg).

Table 2.2: Energy and feed requirements of lactating sows by bodyweight and litter gain.

	Litter Gain (kg/day)			
	2.0 kg		**3.0 kg**	
Sow body weight (kg)	200	300	200	300
Sow maintenance energy (MJ ME/day	24.5	28.9	24.5	28.9
Milk production energy (MJ ME/day)	52.0	52.0	79.6	79.6
Total energy requirement (MJ ME/day)	76.5	80.9	104.1	108.5
Feed required (kg/day)	5.63	5.95	7.65	7.98

Source: Vignola (2009) adapted from Dourmad et al. (1998) (based on diet energy content of 13.6 MJ ME/kg)

From Table 2.2, we can derive that each additional piglet requires 0.56 kg of feed per day to maintain energy balance. Many sows, particularly those in their first and second parity, are challenged to meet these feed intake targets. Therefore, maximizing feed intake in lactation is a key goal of every farm manager. A number of environmental and management factors can be manipulated to improve feed intake in lactation. Several are listed here.

2.4.1 Gestation Feeding

Over feeding in gestation results in lower feed intake in lactation (King et al. 2006; Whittemore 1998; Weldon et al. 1994). In the experiment of Weldon et al. (1994), primiparous sows were given standard (1.85 kg/day) or *ad libitum* access (average daily intake of 3.72 kg) to feed from day 60 of gestation to farrowing and all sows were given *ad libitum* access to feed in lactation. The sows fed *ad libitum* in gestation ate less and lost more body weight in lactation. The total of gestation and lactation feed intake was not different between treatments, indicating a strong inverse relationship between gestation and lactation intake. King et al. (2006) fed five different feed allowances for 35 days starting at day 65 of gestation and found a significant inverse linear relationship between lactation feed intake and daily energy intake in this 35 day period of gestation with an estimated decrease of 113 grams/day of lactation intake per additional MJ of DE per day in gestation feed intake. Fatter sows at farrowing (<21 mm) also have lower lactation feed intake, lose more body weight and have smaller litters at the next parity (Young et al. 2004). However, feed intake in the last 14 days of gestation needs to be increased to prepare the sow for a higher intake in lactation (Whittemore 1998, Vignola 2009).

Loisel et al. (2013) found that feeding a high fiber diet starting at day 91 of gestation followed by a standard lactation diet increased the fat content but not the yield of colostrum or piglet weight gain in the first day postpartum. Survival of low birth weight piglets and overall pre-weaning mortality was improved with the high fiber treatment. The control and high fiber diets were fed to provide the same energy (NE) intake per day. Sow feed intake in lactation was not affected by dietary treatment. Langendijk and Chen (2012) fed 2.5 kg/day of a control or 3.5 kg/day of a high fiber diet during the last month of gestation followed by a standard lactation diet. In this experiment, the additional feed intake in gestation resulted in higher sow weight gain in gestation and reduced sow feed intake and increased body weight loss in lactation.

2.4.2 Lactation Feeding Management

Peng et al. (2007) observed that sows fed using a wet/dry self feeder (*ad libitum* feeding) had a higher total lactation feed intake (120 vs. 110 kg, $P<0.01$) than sows fed by hand twice daily using a dry feeder. Feeding wet feed (by adding water) has also been shown to stimulate intake (Genest and D'Allaire 1995). Leibbrandt et al. (2001) demonstrated that reducing water flow rate from nipple drinkers from 700 ml/min to 70 ml/min reduced lactation feed intake and increased lactation body weight loss of the sow. Moser et al. (1987) reported higher feed intake from day one to six ($P<0.01$) and a tendency for higher intake overall ($P<0.10$) for sows fed ad libitum from 16 hours after farrowing compared with sows on a step-up program where feed was increased by 0.91 kg/day until day six.

2.4.3 Feed Preparation

Increasing the energy density of lactation diets may have a positive effect on daily energy intake of sows, particularly young sows with limited feed intake capacity. Smits et al. (2012) allocated primiparous sows to 5 levels of energy density in their lactation ration (13.0 to 15.3 MJ/kg DE). Treatment diets were fed beginning with 3 kg/day at day 110 of gestation and *ad libitum* during the entire 27 day lactation. Litter size, piglet birth weight, litter gain and daily feed intake in lactation were unaffected by dietary energy level. Sows lost weight in inverse proportion to dietary energy density. Weight and backfat thickness of the sow at weaning increased with increasing energy density. The proportion of sows staying in the herd for a second litter was maximized for feed treatments of at least 14.2 MJ/kg.

Rosero et al. (2011) added varying levels of animal-vegetable fat to the diets of mixed parity sows in summer conditions in Oklahoma ($27 \pm 3^{O}C$). Apparent daily energy intake of sows increased with increasing dietary energy content up to 2.58 Mcal NE/kg . Litter weight gain was improved with a higher fat content of the diet only for parity 3 and higher sows. Feed efficiency of litter gain was reduced with higher fat levels.

Subsequent conception rate and farrowing rate were improved with higher dietary fat levels.

2.4.4 Ambient Temperature

Sows produce a large amount of heat due to their high feed intake and milk synthesis and begin to show increases in respiration rate and skin temperature when housed above 18°C in the lactation period (Quiniou and Noblet 1999). Temperatures beyond 22 °C result in a higher respiration rate to dissipate heat, decreased feed intake and lower litter gain and weaning weight, as well as increased sow weight loss in lactation. In the experiment of Quiniou and Noblet (1999), sows were housed in controlled temperature rooms and the temperature remained constant at the chosen value for 24 hours per day for the duration of lactation.

Williams et al. (2013), using environmental chambers, found that sows subjected to heat stress (24 to 30°C) in lactation had lower feed intake and weaned piglets 0.5 kg lighter than sows maintained at thermoneutral temperatures.

2.4.5 Immune System Activation

Sauber et al. (1999) performed an experiment whereby pairs of littermate primiparous sows raised in conditions of low immune system stimulation were subjected to control or immune stimulation treatments. The immune system stimulation treatment consisted of injection of *Escherichia coli* lipopolysaccharide subcutaneously on days 2 and 10 of lactation. The sows in the treatment and control groups were each allocated 13 pigs per litter and were fed a nutritionally balanced, non-limiting lactation ration. Treatment sows showed a non-significant reduction in lactation feed intake (4.80 vs. 5.36 kg P=0.17) and significant reductions in litter growth rate (2.28 vs. 2.6 kg/day, P=0.01) and daily milk production (10.1 vs. 11.5 kg/day, P=0.01). Sow weight loss in lactation was not affected by treatment.

2.5 Genetic Progress in Maternal Lines

2.5.1 Litter Size

Litter size in pigs is highly variable and has a low heritability of 0.11 (Rothschild and Bidanel 1998). Nonetheless, some selection experiments and even national selection programs, as early as 1973, showed that selection for larger litters could be effective, and litter size started to be included in the selection goals of breeding companies and national recording programs around 1990.

Beginning in 1973, a selection experiment was begun in France which capitalized on a centralized recording program for sow production (LeRoy et al. 1987). Using a large population base of purebred sows enrolled in the French recording program, sows in the top 0.5% of the population for total born/litter were identified as 'hyperprolific' sows. Sons were selected from these sows, put into AI service and used to serve other identified 'hyperprolific' sows. The result of this selection program was an increase of 0.99 pigs total born and 0.88 pigs live born in four generations.

Roger Johnson at the University of Nebraska began a selection experiment in 1967 which selected sows in a composite line for ovulation rate and in later generations for ovulation rate and embryo survival (Johnson et al. 1984). After ten generations of selection for ovulation rate, and one generation of random mating, selection for four generations for litter size resulted in gains of 0.32 to 0.84 over control line sows, depending on parity.

Breeding companies and national genetic evaluation programs began to implement BLUP (Best Linear Unbiased Prediction) genetic evaluations for litter size in the mid 1990's. In Canada, Agriculture and Agri-Food Canada implemented a pilot genetic evaluation for litter size in 1992 and the newly formed Canadian Center for Swine Improvement implemented a regular genetic evaluation for total born per litter in 1995. Selection for litter size using BLUP evaluations has accelerated progress (Figure 2.2) with gains of approximately two pigs per litter in Yorkshire and Landrace breeds on the Canadian Swine Improvement Program since 1995.

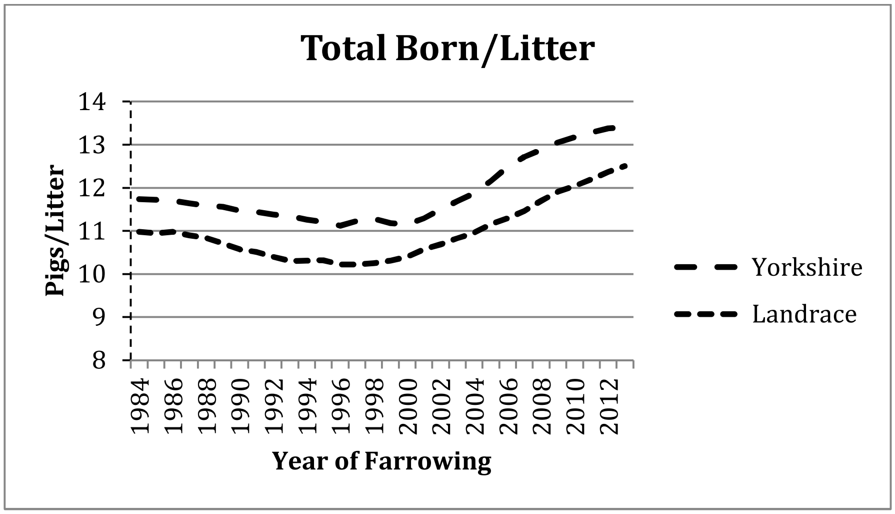

Figure 2.2: Average litter size of nucleus sows on the Canadian Swine Improvement Program. Data from Canadian Center for Swine Improvement (personal communication)

2.5.2 Backfat

Backfat thickness is highly heritable in pigs (Clutter and Brascamp 1998). Introduction of ultrasound equipment for accurate and efficient measurement of backfat was introduced in swine selection programs in the early 1970's and packer payment grids began to reward reduced backfat at about the same time, providing strong motivation for the breeding industry. Selection for reduced backfat has been very effective with reductions of 30% of 1980 backfat levels by 2010 in maternal lines (Figure 2.3).

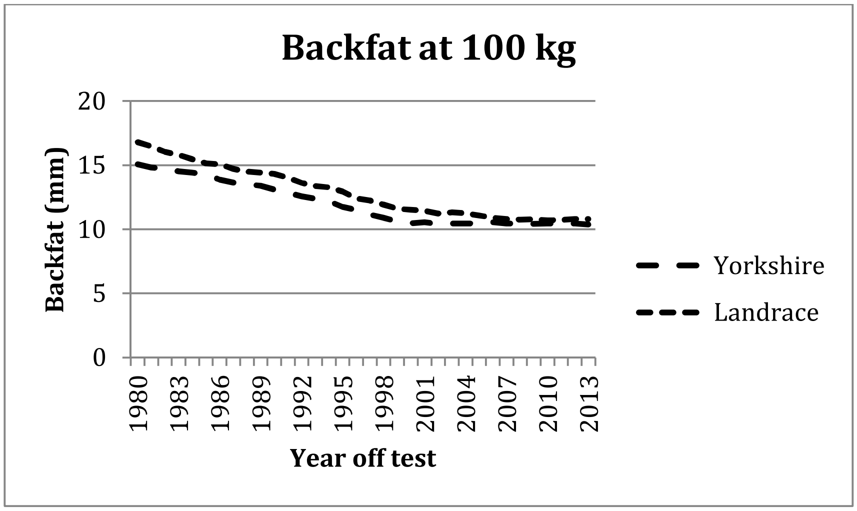

Figure 2.3: Genetic trends for backfat. Data from Canadian Center for Swine Improvement 2014 (personal communication)

2.5.3 Growth Rate

Growth rate is moderately heritable in pigs with a heritability near 0.30 (Clutter and Brascamp 1998) and has been a part of selection goals worldwide for many years. Expressed as the number of days to reach a constant weight of 100 kg live weight, improvement in growth rate has averaged one day per year over 30 years in Canadian breeding herds (Figure 2.4).

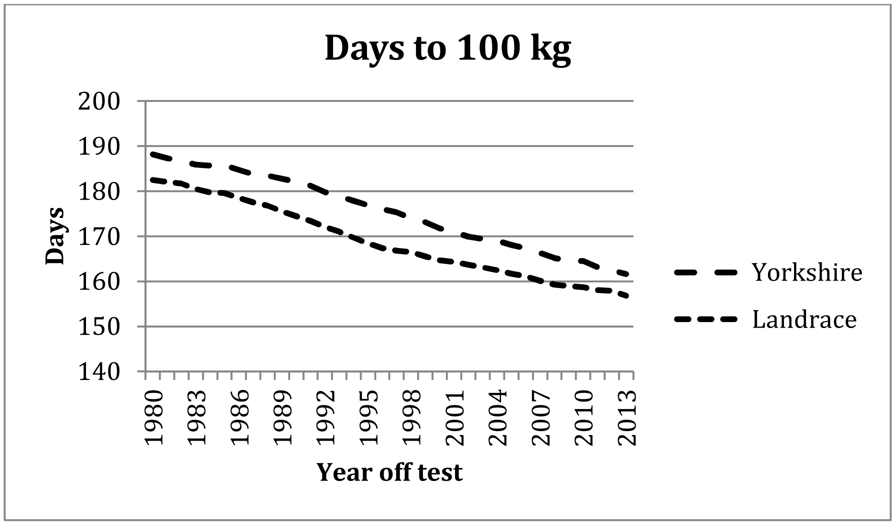

Figure 2.4: Genetic trends for age at 100 kg. Data from Canadian Center for Swine Improvement 2014 (personal communication)

2.5.4 Feed Conversion

Genetic correlations between growth rate, backfat and feed conversion are favorable, so selection for increased growth rate and reduced backfat both result in more feed efficient pigs. Hermesch et al. (2000) found genetic correlations of 0.2 to 0.34 between fat depth and feed conversion depending on the method of measurement of fat depth, and a genetic correlation of -0.7 between test period gain and feed conversion. Johnson et al. (1999) found genetic correlations of -0.32 between daily gain and feed conversion and 0.46 between backfat and feed conversion.

Availability of electronic feed intake recording equipment utilizing Radio Frequency Identification (RFID) tags (Figure 2.5) has greatly improved the efficiency of measuring feed intake and feed conversion. This equipment allows for individual recording of feed intake in group housed pigs by reading individual pig identification and weighing feed as consumed. Previously, recording feed intake was a laborious process which involved locking pigs in stalls for individual recording of feed consumed.

Estimates of genetic trends in feed conversion prior to the introduction of feed intake recording equipment are scarce because feed intake was seldom recorded directly and was often selected as a correlated response to improvement in gain and backfat. However, Tribout et al. (2010) estimated genetic trends in several traits in a French Large White population by using frozen semen to compare boars born in 1977 and 1998. Their estimate of annual genetic trends was -0.014 ± 0.005 kg/kg in feed conversion and +7.6 ± 4.7 grams/day for daily feed intake. After the introduction of feed intake recording equipment, Knap (2009) reported improvements ranging from less than one to five standard deviations of the EBV (1s.d. ≈ 0.04 feed/gain) in different PIC lines from 1998 to 2008, depending on the breeding goals for each line.

Figure 2.5: Example of feed intake recording equipment. Source: Fast Genetics (Saskatoon SK) and Osborne Industries (Osborne Kansas)

2.5.5 Selection and Mature Body Size

Several authors have found that selection for average daily gain during the growth period increases sow body weight (Bunter et al. 2010, Hermesch et al. 2010, Whittemore 1994, Bergsma et al. 2013). Increased body size and leaner sows imply increased sow maintenance requirements (Ball et al. 2008).

2.6 Selection for Feed Intake

Genetic correlations are such that selection for improved feed conversion and reduced backfat has tended to reduce feed intake in the growing pig (Smith et al. 1991; Cameron 1994; Cameron and Curran 1994a; Mrode and Kennedy 1993). Knap (2009) noted a reduction of 30 g/day in feed intake through the 1980's.

Feed conversion, as a ratio of two component traits, presents some difficulty in selection (Gunsett 1984; 1987). Selection theory is such that a trait under selection is expected to have a standard set of genetic parameters, including a constant heritability and additive genetic variance. Feed conversion, as a ratio trait, has two underlying traits, each with their own variance components. As a result, response to selection is not always as predicted (Gunsett 1984).

Gunsett (1984) used Monte Carlo simulation to compare the heritability of a ratio of two normally distributed traits by two common methods. The first method was by correlation among half sib families calculated as four times the sire variance divided by total phenotypic variance. The second method was by realized selection gain given a selection differential. Gunsett (1984) repeated this procedure using simulation for a range of heritability values of the component traits and genetic and phenotypic correlations between traits. He found that estimates of heritability from the sire variance did not reflect realized heritability accurately, and that errors were larger when the selection differential was very high or very low. Gunsett (1984) proposed that ratio traits such as feed conversion should be approached as a linear index of the component traits, rather than the phenotypic ratio. For the ratio of feed to gain, it would be desirable to have a response that maintains or increases gain and decreases feed intake. Such a method would allow the animal breeder to put increased selection pressure on the desired trait (gain in this instance) while limiting change in the other (feed intake).

Kanis and De Vries (1992) proposed methods to optimize intake capacity in the growing pig, using the linear plateau model of Whittemore and Fawcett (1976). The linear plateau model is illustrated in Figure 2.6. In essence, the model says that increased feed intake beyond the maintenance level results in increased protein deposition up to a point, PD_{max}, beyond which protein deposition plateaus and further increases in feed intake result in increased deposition of fat. Optimum food intake is that required to just reach PD_{max}. Kanis and De Vries (1992) developed three different selection indices for scenarios where feed intake capacity was below, above or near levels needed to maximize protein deposition levels. Where intake is too low to realize PD_{max}, an optimum index would involve selection to increase feed intake, resulting in increasing protein deposition and intake. Where intake is higher than that required to achieve PD_{max}, selection emphasis should be on leanness resulting in a reduction of feed intake and growth rate. Where feed intake is close to optimum, selection should be for improved leanness and increased PD_{max}. The value of daily feed intake capacity in these models could be positive, negative or neutral, respectively. The authors noted that this last scenario is the most difficult to achieve and suggested that a desired gains index (Yamada et al. 1975) might be necessary to control changes in daily feed intake.

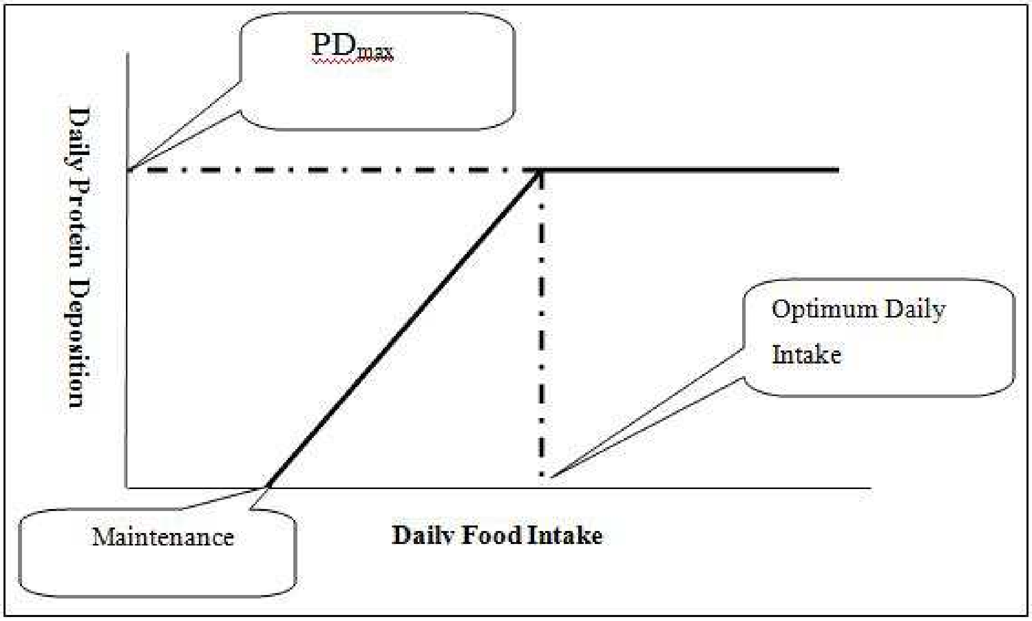

Figure 2.6: Linear plateau model of feed intake and protein deposition. Modified from Whittemore and Fawcett (1976)

Hermesch et al. (2003) developed economic weights for selection indices based on economic and growth (linear plateau) models. They concluded that while economic models always place a negative value on feed intake, growth models value feed intake in relation to optimum intake. However, Hermesch pointed out that while use of such models in selection programs reduces the risk of continually reducing feed intake, such use also requires multiple estimates of intake, weight, and body composition which are difficult to obtain in practice.

In 1985, a large divergent selection experiment was initiated jointly by the University of Edinburgh and Wye College (Webb and Curran 1986; Cameron et al. 1988). The experiment involved two pig breeds (Yorkshire at Edinburgh, Landrace at Wye) and divergent selection on one of four objectives. The four selection objectives were;

(1) Lean tissue growth rate with *ad libitum* feeding;
(2) Lean tissue growth rate with restricted feeding;
(3) Lean tissue feed conversion with *ad libitum* feeding;
(4) Daily feed intake with *ad libitum* feeding.

The experiment ran for eight generations and was followed up by measurements of reproductive performance on the divergent lines (Kerr and Cameron 1995; Kerr and Cameron 1996a, b, c).

Cameron (1994) and Cameron and Curran (1994b) reported results for production traits after four generations of selection in the Yorkshire and Landrace breeds respectively. Selection for lean growth in both breeds resulted in increased growth rate and reduced backfat and feed conversion. Daily feed intake increased in the Landrace and was unchanged in the Yorkshire. Selection for lean feed conversion resulted in reduced backfat and daily feed intake while growth rate was unchanged in both breeds. Selection for increased daily feed intake was successful in increasing daily intake and also increased daily gain and feed conversion. Backfat was increased in the Yorkshire but not in the Landrace breed.

Kerr and Cameron (1995, 1996a, b, c) reported on the first litter performance of gilts from the divergent selection lines after five and seven generations. Gilts from low feed intake lines had a lower conception rate, less backfat at farrowing, lower daily feed intake in lactation and lower litter growth rates. Gilts from the two lines had similar weight and backfat loss in lactation. Similarly, selection for lower lean feed conversion resulted in reduced lactation feed intake and litter growth rate. The authors concluded that selection for reduced feed intake or improved feed conversion impaired reproductive and lactation performance in gilts.

2.7 Genetic Relationships among Traits

Heritability of daily feed intake during the post weaning growth period is moderate, with estimates ranging from 0.2 to 0.45 (Standal and Vangen 1985; Karsten et al. 2000; Johnson et al. 1999; Hall et al. 1999; Mrode and Kennedy 1993). Genetic correlations between daily feed intake and backfat are positive but highly variable between studies. Johnson et al. (1999) found a strong genetic correlation of 0.64 between backfat and daily feed intake, while Mrode and Kennedy (1993) found a genetic correlation of 0.42. Genetic correlations between daily feed intake and growth rate are strong and positive

(Johnson et al. 1999, Hall et al.1999, Mrode and Kennedy 1993). Hence, selection for reduced backfat and increased daily gain would be expected to apply opposing pressures on feed intake. On balance, these relationships appear to support the gradual reduction in daily feed intake from selection for increased growth rate and reduced backfat found by Knap (2009). However, a French experiment (Tribout et al. 2010) that compared progeny of sires born in 1977 and 1998 found a positive genetic trend of 7.6 grams/day/year (P=0.09) in daily feed intake. Genetic correlation estimates between daily feed intake and feed conversion are generally positive, indicating that selection for improved feed conversion will result in reduced daily feed intake.

Heritability estimates for lactation feed intake have generally been moderate and variable, but different studies have used different genotypes and substantially different lactation lengths. Studies conducted in Europe and Australia, which are the most common in the literature, have generally used a lactation length of 28 to 30 days, longer than the 18-23 days usually practiced in North America. Bunter et al. (2010b) found a heritability of 0.15 in parity 1 and 0.24 in parity 2 with a targeted lactation length of 30 days. Hermesch et al. (2010) found a heritability of 0.10 for a 10 day measure of feed intake between day 5 and 14 of lactation in mixed parity sows. Hermesch et al. (2008), with a different data set, estimated the heritability of average daily feed intake in a 21 day lactation at 0.14, with somewhat higher estimates of 0.17 and 0.18 for intake measured during the first or second week after day four in mixed parity sows. Hermesch (2007) found the heritability for total lactation feed intake and average lactation intake to be 0.19 and 0.17 respectively.

Hermesch (2007) found a large permanent environmental effect of the sow, of a similar magnitude to heritability, of 0.18 and 0.17 for total and average daily lactation feed intake respectively. In contrast, Bergsma et al. (2008) found a higher heritability of 0.30 for total lactation intake under ad lib feeding and a smaller permanent environmental effect of the sow of 0.04. Hermesch (2007) also found repeatability between lactations of 0.45 and concluded that lactation feed intake in gilts is a different trait than that of later parity sows.

It is common industry practice to feed sows, and especially young sows, a gradually increasing allowance of feed in the first five to seven days of lactation, before introducing ad lib feeding. Sows need some time to adjust to the large change in feed intake from gestation to lactation and it is felt that a gradual increase to full ad lib feeding can help reduce incidents of feed refusal. Hence, excluding this period of restricted intake in early lactation, as suggested by Hermesch (2007), may result in a more accurate estimate of voluntary feed intake in lactation.

Genetic correlations between daily feed intake in the post weaning growth period and in lactation have been generally positive but also quite variable between studies. Bunter et al. (2010) estimated genetic and phenotypic correlations between daily feed intake and feed conversion in a post selection growth period and lactation feed intake. She found positive but non-significant values of 0.26 and 0.07 for genetic and phenotypic correlations respectively for first parity sows, and significant values of 0.39 and 0.10 respectively for second parity sows. Correlations with post selection feed conversion were non-significant for both parity groups. Rauw et al. (2008) found a phenotypic correlation of 0.50 ($P < 0.01$) between growth period intake and lactation intake in a mouse line selected for large litters and raising the birth litter. The correlation remained significant at 0.36 ($P<0.05$) when the litter size was standardized to 8 pups. On the other hand, Bunter et al. (2007) in an earlier study reported a surprising negative but non-significant (r_a= -0.26 ± 0.33) genetic correlation between intake in the growth period and in lactation in sows. Bergsma et al. (2013) found a modest positive genetic correlation of 0.23 between daily feed intake in the growing period and daily feed intake in lactation and a higher genetic correlation of -0.51 between residual feed intake in finisher pigs and lactation efficiency.

Genetic correlations between other production traits and lactation performance measures have also been reported. Hermesch et al. (2010) reported significant ($P<0.05$) regression coefficients between EBV for average daily gain (ADG) in the post weaning growth period and lactation feed intake (0.004 kg lactation feed intake /g ADG EBV), sow body weight at farrowing (0.3 to 0.32 kg /g ADG EBV) and backfat thickness at farrowing (0.2 mm/g ADG EBV). Other authors have reported positive correlations between average daily gain in the growth period and lactation feed intake (Kerr and Cameron 1996c; Bunter et al. 2010). Genetic correlations between backfat at the end of test and lactation feed intake have generally been reported as near zero. For example, Hermesch et al. (2010) found a genetic correlation of -0.35 ± 0.27 between off-test backfat thickness and lactation feed intake. Bergsma et al. (2013) reported a high positive genetic correlation of 0.53 between off-test backfat and sow backfat at farrowing.

2.8 Residual Feed Intake and Sow Performance

Residual feed intake is defined as feed intake after the animals predicted needs for growth and sometimes backfat and metabolic body weight are accounted for, and can be calculated by use of published estimates of requirements for these components or, alternatively, as the residual of a model that includes these traits (Mrode and Kennedy 1993). Genetic correlations between daily feed intake and residual feed intake are high and positive (Dekkers and Gilbert 2010; Mrode and Kennedy 1993). Residual feed intake should be independent of growth rate and backfat by definition, but genetic correlations have not always been zero when adjustments for growth and backfat are done at the phenotypic level. Kennedy et al. (1993) proposed that the adjustments be made based on genetic parameters of the traits rather than phenotypic estimates. Selection for reduced residual feed intake results in reduced backfat and daily feed intake in the growth period (Gilbert et al. 2007; Cai et al. 2008)

Selection experiments on residual feed intake have been carried out by Iowa State University (Cai et al. 2008) and by INRA (Gilbert at al. 2007) and both studies included measurements of sow reproductive traits for the high and low residual feed intake lines. The INRA experiment was a divergent selection experiment with one line selected for high and the other for low residual feed intake, reported after 7 generations. The Iowa State experiment had a line selected for low residual feed intake and a control line unselected for the first five generations and selected for high residual feed intake in the sixth generation.

Both studies found positive effects of selection for low residual feed intake on sow production traits. In the Iowa State University data (Young et al. 2010), the low residual feed intake line had higher total born (13.2 vs. 11.5, P<0.001), higher number weaned (9.6 vs. 8.7, P=0.03), higher birth weight adjusted for total born (15.8 vs. 14.8 kg, P<0.01) and higher litter weaning weight (55.9 vs. 51.4 kg, P<0.01). The Iowa State experiment did not report lactation feed intake. In the INRA data set (Gilbert et al. 2011) selection for low residual feed intake reduced sow daily feed intake (4.54 vs. 4.82 kg/day, P<0.01), increased number of piglets at birth (12.7 vs. 12.1 P<0.01) and litter growth rate to 21 days (46.1 vs. 44.1 kg, P<0.01). However, in both experiments, sows from the selected lines lost more weight and more backfat during lactation to support the larger, faster growing litter. Due to facility constraints, neither research group was able to measure lifetime productivity or rebreeding efficiency, leaving questions about the effect of selection for reduced residual feed intake on lifetime performance.

The INRA investigators (Gilbert et al. 2012) also computed sow residual feed intake as the difference between observed daily feed intake and that predicted for maintenance and production where predicted feed intake was calculated by a multiple regression that included change in sow body weight, backfat, litter growth, and metabolic weight at weaning. Sow residual feed intake was responsible for only 24% of the phenotypic variation in sow daily feed intake, somewhat lower than the 30-50% of variation in daily feed intake in growing pigs (Dekkers and Gilbert 2010, Mrode and Kennedy 1993). Heritability for sow residual feed intake was estimated at 0.14 ± 0.06 vs. 0.26 ± 0.07 for sow daily feed intake in the INRA study. These authors also recommended computing sow residual feed intake between day 5 of lactation and weaning, avoiding the early lactation step up feeding period.

2.9 Lactation Efficiency

Bergsma et al. (2009) defined ‘Lactation Efficiency’ as the ratio of lactation output (litter weight gain and maintenance) to inputs (energy from feed intake plus energy from sow body fat and protein mobilization). Lactation efficiency was estimated to be lowly heritable (0.14) and averaged 65 and 68% at two farms. In other words, 65 and 68% respectively of sow feed intake above maintenance was used for the productive outputs of gain and maintenance of the litter. Sows with higher lactation efficiency had lower feed intake, lower backfat loss, higher energy output, higher piglet growth rate and lower piglet mortality in their litters. Body weight loss and protein loss were uncorrelated with lactation efficiency. The authors suggest that selection for lactation efficiency could improve feed conversion of sows and mitigate possible problems associated with insufficient lactation intake.

Calculation of lactation efficiency requires measurement of lactation feed intake, energy content of feed, weight of piglets born and weaned, weight of dead piglets, and backfat and weight loss of the sow in lactation. Input and output respectively are calculated as:

Input = (Energy from total lactation feed intake
+ energy from fat mobilization of the sow
+ energy from protein mobilization of the sow
+ Energy needed for maintenance of the sow)
/ lactation days

Output = (Energy in fat deposition in weaned piglets
+ energy in protein deposition in weaned piglets
+ energy in fat deposition in piglets that died
+ energy in protein deposition in piglets that died
+ energy for maintenance of piglets weaned
+ energy for maintenance of piglets that died)
/ lactation days

Lactation efficiency (%) = Outputs / Inputs * 100

Calculation of lactation efficiency requires the collection of a considerable amount of data and several components of the calculation are subject to error in estimation. The authors performed a sensitivity analysis and determined that errors in estimating the energy density of feed led to the largest error. An error of 10% in estimating energy density changed the estimate of lactation efficiency by nearly 10% from 62.8% to 57% for a hypothetical average sow. Due to estimation errors, a small number of sows in both farms had estimated lactation efficiency of greater than 100%. Selection for lactation efficiency also carries some risk, because a decrease in inputs such as feed intake or an increase in outputs both improve lactation efficiency with potentially very different long term results (see the discussion regarding selection on a ratio above). Bergsma also found that sows with better lactation efficiency had lower lactation feed intake.

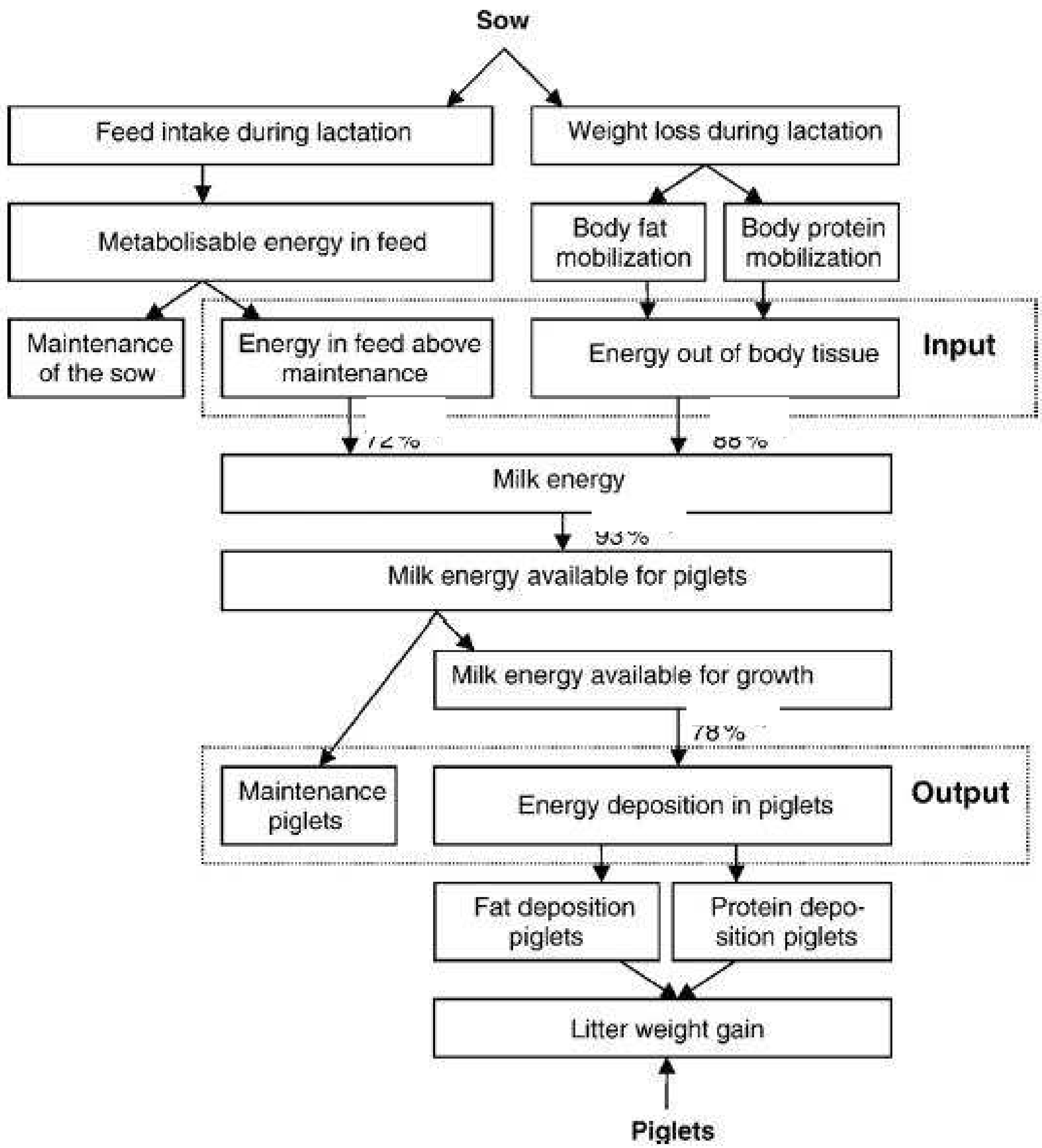

Figure 2.7: Model of energy flow in the lactating sow. Modified from Bergsma et al. (2009)

2.10 Summary

Feed intake in lactation is important in order to maintain sufficient body condition and prevent delayed rebreeding, a smaller subsequent litter, and early removal from the herd due to reproductive or locomotive failure.

Long term selection for reduced backfat, faster growth and more recently, improved feed conversion have resulted in a larger and leaner sow with less body reserves of fat and increased maintenance needs. Selection may have also reduced feed intake, although literature reports are not unanimous in this regard. Literature reports on the relationship between traits in the growth period and lactation feed intake are also not unanimous. Selection for growth has been reported by some authors to improve lactation feed intake, while correlations between feed intake in the growth period and in lactation have been widely variable, from -0.26 (Bunter et al. 2010) to +0.39 (Bergsma et al. 2013) in pigs and +0.50 in a mouse model (Rauw et al. 2008). Genetic correlations between backfat and growing period feed intake have been found to be positive, while those between backfat and lactation feed intake have been variable. It appears that selection in some traits such as growth rate may have a positive effect on lactation feed intake while selection in others such as reduced backfat and improved feed conversion may have tended to reduce lactation intake.

Two experiments involving experimental lines selected for residual feed intake have investigated the effects of this selection on sow productivity traits. Both found that lines selected over generations for lower residual feed intake had more piglets and larger piglets at birth and higher litter gain from birth to weaning, but at the expense of higher weight and backfat loss in sows. Neither experiment was able to measure rebreeding success or lifetime productivity of sows and the long term effect of such selection on sow longevity and productivity are unknown.

It is of critical importance for pig breeders to understand the effects of lactation feed intake on longevity and long term productivity of their maternal lines, as well as the genetic parameters influencing lactation feed intake. It appears that the traits included in current selection goals may exert opposing forces on feed intake in the growing period, with selection for growth rate tending to increase feed intake and selection for leanness and feed conversion tending to reduce feed intake. It is therefore very important for pig breeders to also understand the relationship in their genetic lines between feed intake in the growing pig and feed intake in lactation. Estimates of this relationship in the literature are widely variable, with some positive and some negative genetic correlations reported. However, the literature reports are in agreement that the correlation between growth period feed intake and lactation feed intake are far from unity. Hermesch (2007) suggested that lactation feed intake in parity one is a different trait under different control mechanisms than intake in later parities.

While genetic nucleus herds tend to turn generations rapidly in order to maximize genetic progress, they also need to produce a commercial female with a long and trouble free productive lifetime. Measurement of sow longevity is difficult in a nucleus herd because many sows are culled for reasons of genetic value prior to reaching the end of their normal productive lifetime. Genetic evaluations for longevity can be improved by inclusion of records from multiplier sows or commercial F1 sows where culling on genetic value is reduced or not practiced at all, but maintaining accurate pedigree records and collecting quality data at the commercial level is problematic. Indicator traits for sow longevity that are expressed early in life, especially at selection age would be helpful in improvement of sow longevity. It may be that EBV for traits such as growth rate, backfat or feed intake in the growth period are predictive of sow longevity. Lactation feed intake and sow weight loss are not commonly measured in nucleus herds, but recent technology such as electronic feeders for farrowing rooms mean that recording these traits is now feasible if they are of value in predicting sow productive life.

Recent years of high feed prices have accentuated interest in a feed efficient pig, both in the growing period and as a productive sow. However, improvement in feed conversion must be attained while minimizing collateral damage to sow productivity and longevity. This research will focus on the value of measuring lactation feed intake in parity 1 and 2 to predicting future productivity and longevity of sows, the relationships between traits measured in the growing period and lactation feed intake, and the relationship between currently calculated EBV and sow longevity.

This research will investigate specifically:

(1) The effect of lactation feed delivery and patterns of delivery on subsequent reproductive performance and measures of productive lifetime of the sow.
(2) The relationship between daily feed intake in the growth period and in feed delivery in lactation.
(3) Relationships between other phenotypes such as growth rate and backfat measured on selection candidates in the growing period and sow feed intake and sow longevity.
(4) The relationship between the various estimated breeding values computed for nucleus pigs and lactation delivery and sow longevity.
(5) The possibility of developing an index of existing or new traits that might predict sow longevity.

3. MATERIALS AND METHODS

3.1 Animal Care

Data for this project was provided by a breeding company nucleus farm in Saskatchewan operating under the then current Canadian Code of Practice for Pigs (Connor 1993).

3.2 Selection of Gilts

Selected nucleus replacement gilts of three purebred maternal genetic lines, Landrace (LA), Yorkshire-A (Y-A) and Yorkshire-H (Y-H), were placed on Feed Intake Recording Equipment (FIRE)(Osborne Industries, Osborne KS) for an estimate of daily feed intake in the late finisher stage of growth. The Yorkshire-H and Landrace lines are of largely Canadian origin, while the Yorkshire-A line is a French line resulting from the French 'hyper-prolific' selection program described earlier herein (Le Roy et al. 1987). From 6715 gilts weighed off-test from February through August of 2010, 675 gilts were selected based on EBV Index and non-index criteria including an assessment of conformation and absence of defects in their birth litter. The selected gilts were weighed off-test at an average of 146 days of age and 97.5 ± 8.0 kg in weight. At off-test, ultrasound measurements of backfat and loin depth were taken at a site between the third and fourth last ribs, 5 cm laterally from the midline on the right side by technicians certified by the Canadian Swine Improvement Program (Maignel and Daigle 2007) using real time ultrasound equipment (Vetko Plus, DGF Equipment, Quebec QC).

The index used for selection of gilts included trait EBV for growth rate, lean yield, feed conversion, litter size (defined as pigs alive at day 2 after farrowing and greater than 800 grams in birth weight), weaning to conception interval, weaning weight and number weaned per litter. At selection, some trait EBV on selection candidates are parent average EBV since selection candidates do not have their own record for all traits in the index. The EBV for feed conversion at selection was based on individual feed intake records on male relatives of the gilts, but not the records of the gilts themselves.

Similarly, at selection, the EBV for the maternal traits of litter size, weaning to conception interval, weaning weight and number weaned were parent average EBV calculated from records of female relatives.

Following selection, gilts were mixed into groups of 14 or 15, placed in pens equipped with FIRE feeders and allowed 3 or 4 days to adjust to the new pens, pen mates and feeders. Following the adjustment period, gilts were tagged with Radio Frequency Identification (RFID) tags and weighed, then returned to the feed recording pens. Individual feed intake was recorded for 15 to 23 days and the gilts were again weighed. Nutrient specifications of the finisher diet are shown in Appendix A.

Feed intake data including weight of feed dispensed was captured for each feeder visit by the feed recording equipment. Visit data was cleaned for machine recording errors using the methods of Casey et al. (2005) and summed into daily values for feed intake. Average daily intake was then calculated and adjusted to a standard base using a mixed model (Proc Mixed, SAS 9.2) which included the fixed effect of genetic line, linear covariates of days on the feeder and starting weight, and random effects of end date and pen group. Following data cleaning and adjustments, daily feed intake records greater than two standard deviations from the mean daily feed intake were removed as outliers, leaving 640 of the original 675 animals with feed intake records.

Following feed intake recording, gilts entered the standard gilt development program of the nucleus herd. Gilts were placed in group pens in the gilt development area of the barn, fed a gilt gestation ration *ad libitum* and checked for heat daily by walking a boar through the pen. At approximately 210 days of age, the gilts were moved to individual gestation stalls for breeding and fed a gilt gestation ration at 2 to 2.3 kg daily. Gilts were bred by artificial insemination to boars of the same genetic line at an average of 223 ± 13.7 days of age. All gilts had at least one recorded heat with no service prior to breeding.

Because the nucleus herd has a large proportion of gilts and young sows, a single gestation ration formulated for gilts is fed to all sows throughout the breeding and gestation period. At approximately day 100 of gestation, feed allowance is increased to 3 kg daily. Nutrient specifications for the gestation diet are shown in Appendix A.

It is the normal practice of the nucleus herd to select more gilts at off-test than are required for nucleus replacements. Prior to first service, a second selection is made based on EBV index, size and conformation at approximately 200 days of age. Accordingly, of 675 gilts initially selected and placed on FIRE feeders, 577 farrowed a first litter. Of the 98 gilts that did not farrow a first litter, 67 were removed for voluntary reasons related to herd management and genetic improvement and the remaining 31 gilts were removed as non-breeders. The remaining gilts became a part of the nucleus herd and were subjected to normal nucleus feeding and management practices.

3.3 Recording Sow Productivity

Sow productivity data recorded included 'heat no serve' dates, services, pregnancy checks, litters, fostered pigs, piglet deaths and number of piglets weaned. Piglets, including still born piglets, were weighed individually at birth and total litter weights were taken at weaning. Piglets were recorded as born alive, stillborn or mummified at birth. Total born per litter was defined as born alive plus stillborn piglets. An extended weaning to conception interval was defined as an interval greater than 7 days and not more than 30 days. Sows with a weaning to conception interval of greater than 30 days were excluded from the analysis of weaning to conception interval.

3.4 Recording Lactation Feed Delivery

Daily feed delivery in lactation was recorded for the first two parities. The farm follows a step up lactation feeding program. First parity sows were started at 3 kg/day after farrowing and feed was gradually increased to day seven. After day seven, feeding was *ad libitum.* Second parity and older sows were increased more rapidly, reaching ad libitum feeding by day 5 after farrowing.

Farrowing pens were equipped with a self feeder (Crystal Spring Hog Equipment, St. Agathe, MB) holding approximately 12 kg of feed and equipped with a nipple type drinker which allowed the sow to consume her feed in wet or dry form. Feed was delivered by an auger system and measured volumetrically via a calibrated dropper tube. The amount of feed delivered each day was recorded manually on a paper chart in front of each sow. Any feed removed from the feeder was estimated visually and recorded on the same chart. A full dropper tube holds approximately 11 kg. Sows eating more than 11 kg daily were topped up with an additional 2 or 3 kg of feed in the afternoon. Figures 3.1 and 3.2 show the feeder and dropper tubes used. Because of the holding capacity of the feeder, feed was recorded as delivered, not necessarily as consumed. Maximum daily temperature was recorded for each farrowing room each day and used in a mixed model to develop a predicted daily feed intake curve for each genetic line and parity.

Sows enter the farrowing room at 2 to 8 days before farrowing. From entry to the farrowing room until farrowing day, they are fed lactation ration at 3 kg daily. Sows and gilts in gestation are fed a gestation ration at approximately 2.4 kg per day. This allowance is increased to 3 kg per day for the last 2 weeks of gestation.

Figure 3.1: Crystal Spring Lactation Feeder

Figure 3.2: Calibrated Feed Delivery Tube

Sows were fed a lactation diet with NE of 2450 kcal/kg and total lysine of 1.17%. Lactation diet specifications and major ingredients are shown in Appendix A. Mean length of lactation was 19.2 ± 3.1 days for parity 1 and 18.3 ± 2.3 days for parity 2 sows. Average daily feed delivered over the entire lactation was 6.8 kg in parity 1 and 8.3 kg in parity 2. Lactations less than 14 days in length represented a feed intake or illness problem and these lactations ended in the litter being fostered to another sow rather than weaned. Sows in this group were always culled and their records were excluded from the analysis of lactation feed intake effects on future rebreeding or litter performance.

Sow feed delivery up to day 21 was used in a prediction model for daily feed intake, which in turn was used to identify what was defined as a transient reduction in feed intake. For estimation of the effects of average daily lactation feed delivery on future performance, intake up to day 14 only was used. Since some litters were weaned starting at day 15, lactation delivery up to day 14 was used in order to include the maximum number of sows in the analysis.

Following weaning, sows were placed in individual stalls and checked for estrus daily by walking a boar in front of the stall. Following standard practice at this herd, all parity 1 sows were treated at weaning with 400 IU of pregnant mare serum gonadotropin and 200 IU of human chorionic gonadotropin (PG600, Intervet Inc., Millsboro, DE) to encourage a return to estrus. Weaned sows were served at the first standing heat by artificial insemination to boars of the same genetic line.

3.5 Modeling Lactation Feed Intake

As reviewed in this thesis, previous authors have found that average or total feed intake during lactation affected the length of productive life of the sow, weaning to conception interval and litter size in the subsequent litter. Furthermore, some authors have reported that patterns of feed intake sometimes had significant effects on future performance. Different authors have used different measures of reduced lactation feed intake and patterns of feed intake (Anil et al. 2006; Schinkel et al. 2010). Two such measures were employed in this study to determine if feed refusal or a transient drop in feed intake during lactation affected subsequent reproductive performance or length of productive life. First, one or more days of zero delivery were recorded as a binary variable and the effect on future performance was estimated. Second, a regression model was developed to predict a lactation feed delivery curve based on linear, quadratic and cubic effects of day of lactation, farrowing room temperature, litter weaning weight and number weaned within each line and parity. Following the method of Schinkel et al. (2010), delivery more than 1.6 times the residual standard deviation (approximately 3 kg) below the predicted delivery for that breed and parity class for two consecutive days was considered a drop in intake and was analyzed as a binary variable.

Response variables representative of future reproductive performance were identified including occurrence of the next litter, occurrence of an extended weaning to conception interval and number of piglets total born. For the binary response variables (occurrence of the next litter, extended weaning to conception interval), logistic regression (Proc Logistic, SAS 9.2) was used to provide an odds ratio for predictor variables. For the linear response variable of total born in the next litter, a mixed model was used (Proc Mixed, SAS 9.2). Separate models were used to estimate the effects of one or more feed delivery reductions, one or more zero delivery days, or low daily feed delivery in the first 14 days of lactation. Parity groups were analyzed separately with breed included in each model.

3.6 Lifetime Performance

Lifetime performance was recorded for all gilts in the original data set, including age at removal, number of parities completed and total number of pigs weaned. A linear model (Proc Mixed, SAS 9.2) was used to estimate the effect of parity 1 and parity 2 lactation feed delivery on lifetime performance, measured as length of life in days, number of parities completed and total pigs weaned. In addition, two binary response variables were defined as whether or not the sow had successfully completed parity 3 and parity 4 (stayability to parity 3 or 4). Logistic regression (Proc Logistic, SAS 9.2) was used to estimate first and second lactation feed delivery effects on stayability to parity 3 and parity 4. Because of the nucleus practice of voluntary removal of sows for low index, the sows EBV index at each parity was included as a linear covariate in both linear and logistic regression models. EBV index was highly significant for all lifetime productivity traits recorded, while the genetic line of the sow was not significant for any lifetime productivity trait.

3.7 Models and Software

Cleaning and preparation of all data was done using SAS 9.2 (SAS Institute Inc. 2008). Growth period feed intake data was cleaned for recording errors and summed into daily intake values using the methods of Casey et al. (2005). For analysis of the effects of lactation feed delivery on measurements of future productivity, longevity or stayability, where the response variable was binary in nature, logistic regression was used (Proc Logistic, SAS 9.2) and where the response variable was linear in nature, a mixed model was chosen (Proc Mixed, SAS 9.2). In all cases a threshold of $P<0.05$ was considered a significant result, except for the stepwise regression model (Proc Reg, SAS

9.2) prediction of sow longevity measures, where a P value of 0.15 was the threshold for inclusion in the model.

Genetic parameters were estimated using ASReml 3.0 (Gilmour et al. 2009) for the entire breeding company population which included the gilts for which feed delivery was recorded in this study. Two separate animal models were constructed, one each for maternal and growth period trait groups. A univariate analysis was completed for each trait to estimate variance components, heritability and permanent environmental effects of dam (for maternal traits) or litter (for growth period traits) and to arrive at initial values of variance components for bivariate analysis. Subsequently, a bivariate analysis was conducted on each pair of traits within the maternal and growth models to estimate phenotypic, additive genetic and residual correlations. Growth traits included average daily gain, backfat, loin muscle depth, daily feed intake and feed conversion. Maternal traits included litter size alive at day 2, weaning to conception interval (following parity 1 only) and weaning weight of the litter. Due to the small number of lactation feed intake records in this data set, it was not possible to estimate genetic parameters or compute an EBV for lactation feed intake.

Using the genetic parameters above, estimated breeding values were computed using two separate multi-trait animal models with growth traits and maternal traits computed separately. EBV were computed using PIGBLUP V6.0 (Crump et al. 2009). All animals in the population born since January 1st, 2000 were included in each genetic evaluation run. The base for all the trait EBV was a period of 1100 days ending 180 days prior to the EBV run date. Since there were pedigree connections between the two Yorkshire lines, they were grouped together in a single genetic evaluation run while Landrace animals were evaluated in their own group.

Selection of gilts and keep or cull decisions on sows are made based on regular genetic evaluations run weekly by the breeding company. Accordingly, gilts in this data set were selected on an index of EBV computed immediately following their off-test date. Following each litter, a keep or cull decision on each sow was made, based in part on their then current EBV index.

After all the females in this data set had completed their productive life and been removed from the herd, the genetic parameters described herein were estimated and a final set of EBV computed using these parameters. These final EBV were then used for the comparisons with lactation feed delivery and productivity measures listed herein. It should be noted that these EBV would be the most accurate available on the females in this data set since they were calculated after the end of their productive life, included growth and maternal trait measurements on their progeny and feed intake records on sons as well as feed intake records on the gilts themselves. Further, this final set of EBV were computed using current genetic parameters estimated in this paper from the actual population involved. Table 3.1 describes the size of the population and number of records included in the final EBV run.

Feed intake records captured on this set of gilts were included in the final genetic evaluations for feed intake but not for feed conversion. Recording feed intake using FIRE feeders for a 17 day period was considered a relatively accurate estimate of daily feed intake in the late finisher period of growth. However, estimates of growth needed to compute feed conversion are inaccurate when based on a short time period.

Table 3.1: Number of records included in genetic evaluations

	Landrace	**Yorkshire**
Animal pedigrees	119,952	182,348
Growth traits		
Average daily gain	111,800	158,348
Ultrasound backfat and loin depth	86,758	132,929
Feed intake	6,292	6,995
Litter traits		
Born per litter	145,086	204,238
Weaning to conception interval	21,331	35,477
Litter weaning weight	16,998	15,055

4. RESULTS AND DISCUSSION

4.1 Growth Period Phenotypes

After being weighed off-test, selected gilts were grouped and placed in pens equipped with feed intake recording equipment for a test period averaging 17 days. Descriptive statistics for off-test age, weight and ultrasound backfat and loin depth measurements, as well as feed intake on the FIRE feeders is shown in Tables 4.1 and 4.2.

Table 4.1: Descriptive statistics of selected gilts and contemporaries

	Selected Gilts (n=675)		All Gilts (n=6712)	
	Mean	Std. Dev.	Mean	Std. Dev.
Age off-test (days)	146.0	2.81	146.1	3.1
Weight (kg)	97.5	8.0	94.1	9.1
Fat depth (mm)	10.8	2.1	10.8	2.3
Lean depth (mm)	57.1	4.5	56.0	5.0

Table 4.2: Finisher period feed intake (n=640 gilts)

	Mean	Std Dev.	Min	Max
Days on feeder	17.1	1.6	15	23
Start weight (kg)	98.4	8.5	78	125
End weight (kg)	113.8	9.3	88	146
Gain (kg)	14.9	4.7	-4.0	37.5
Daily feed intake (kg)	2.65	0.43	1.63	3.69

(35 gilts from the original group with feed intake greater than ± 2 standard deviations from the mean were removed as outliers)

4.2 Sow Productivity

Standard measures of sow productivity including piglets born alive, stillborn, mummified piglets, number weaned and litter weaning weight were recorded for all parities. Means and standard deviations for each trait are shown in Tables 4.3 through 4.5 for Landrace, Yorkshire-A and Yorkshire H respectively.

Table 4.3: Productivity for Landrace sows

	Parity 1	**Parity 2**	**Parity 3+**
Litters	244	131	253
Born alive	11.91 (2.89)	11.73 (3.58)	13.19 (2.81)
Stillborn	0.92 (1.51)	0.51 (1.08)	1.26 (1.44)
Mummies	0.20 (0.52)	0.21 (0.59)	0.46 (0.97)
Piglets weaned	9.79 (1.53)	10.44 (1.35)	10.65 (1.54)
Weaning weight (kg)	61.3 (12.7)	69.8 (13.3)	68.0 (12.6)
Weaning age (days)	20.7 (2.4)	19.5 (1.5)	18.6 (1.8)

Mean (standard deviation)

Table 4.4: Productivity for Yorkshire-A sows

	Parity 1	**Parity 2**	**Parity 3+**
Litters	173	107	211
Born alive	12.54 (3.52)	12.78 (3.83)	14.24 (3.42)
Stillborn	1.15 (1.52)	1.01 (1.22)	1.88 (1.84)
Mummies	0.23 (0.61)	0.20 (0.48)	0.45 (0.83)
Piglets weaned	10.16 (1.56)	10.75 (1.21)	10.84 (1.53)
Weaning weight (kg)	59.8 (13.5)	69.4 (11.3)	67.1 (12.0)
Weaning age (days)	21.7 (2.5)	20.8 (1.4)	20.7 (1.5)

Mean (standard deviation)

Table 4.5: Productivity for Yorkshire-H sows

	Parity 1	**Parity 2**	**Parity 3+**
Litters	91	50	113
Born alive	11.01 (3.22)	12.16 (3.89)	12.42 (3.55)
Stillborn	1.02 (1.34)	1.06 (1.65)	1.13 (1.59)
Mummies	0.34 (0.98)	0.26 (0.69)	0.30 (0.64)
Piglets weaned	9.97 (1.57)	10.58 (1.21)	10.58 (1.69)
Weaning weight (kg)	61.6 (13.7)	69.3 (11.33)	69.7 (13.5)
Weaning age (days)	21.4 (2.4)	20.6 (1.2)	20.3 (1.9)

Mean (standard deviation)

4.3 Sow Productive Lifetime and Removals

Typical of a nucleus herd, this farm has a targeted 100% annual replacement rate in contrast to a normal commercial target of 40-50%. Since the herd averages 2.5 litters per sow per year, the implied average productive lifetime of a female is 2.5 litters. A small number of productive older sows were moved to a nearby multiplier farm operating under the same management and feeding program and litter records in the second farm were counted toward lifetime productivity. Some young sows were removed for low EBV index and developing feet and leg conformation problems. For the purposes of this analysis, sow removals were classified into voluntary (planned) and involuntary (unplanned) removals. Voluntary removals include the sub categories of Genetics (EBV index) , Conformation and Other (Figure 4.1). In addition, the category of Old Age was considered a voluntary removal. Involuntary removals were grouped into the categories of Reproduction, Productivity, Condition/Lameness and Other (Figure 4.2). Using this classification there were 432 voluntary removals (64%) and 243 involuntary removals (36%) in the data set. Among involuntary removals, reproduction problems accounted for 29% of the involuntary removals, near the average of the 5 studies shown in Table 2.1 in the literature review. Condition or lameness accounted for another 20% of involuntary removals, also near averages reported in the literature (Englblom et al. 2010; Englblom 2008).

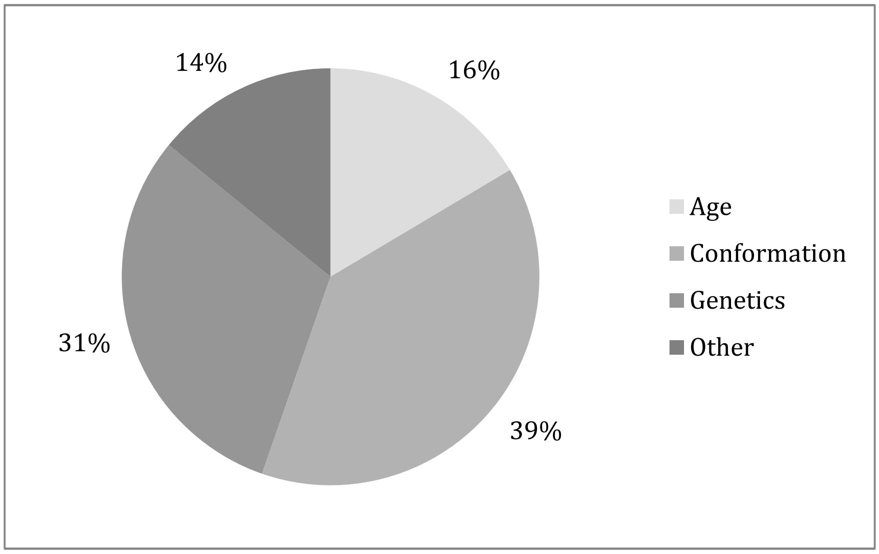

Figure 4.1: Breakdown of voluntary removals by reason

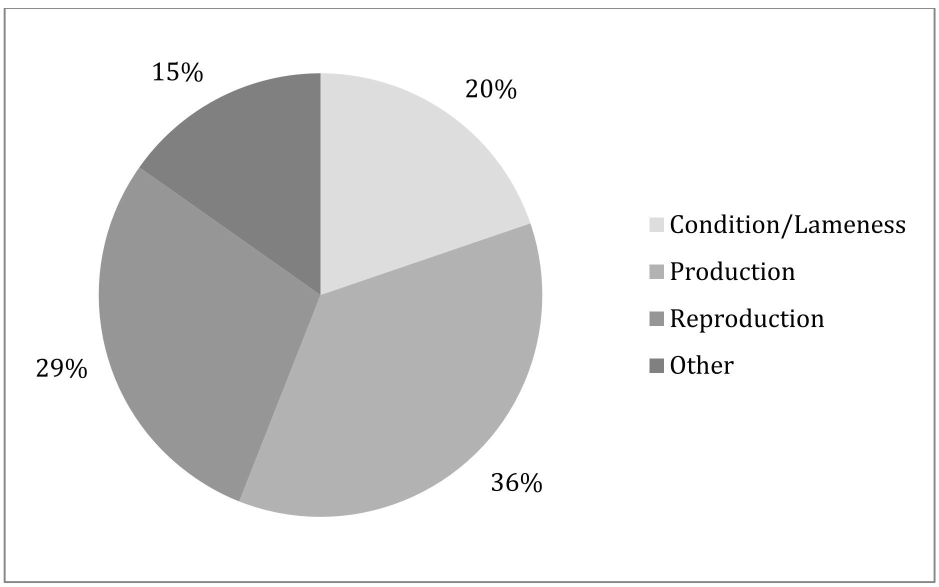

Figure 4. 2: Breakdown of involuntary removals by reason

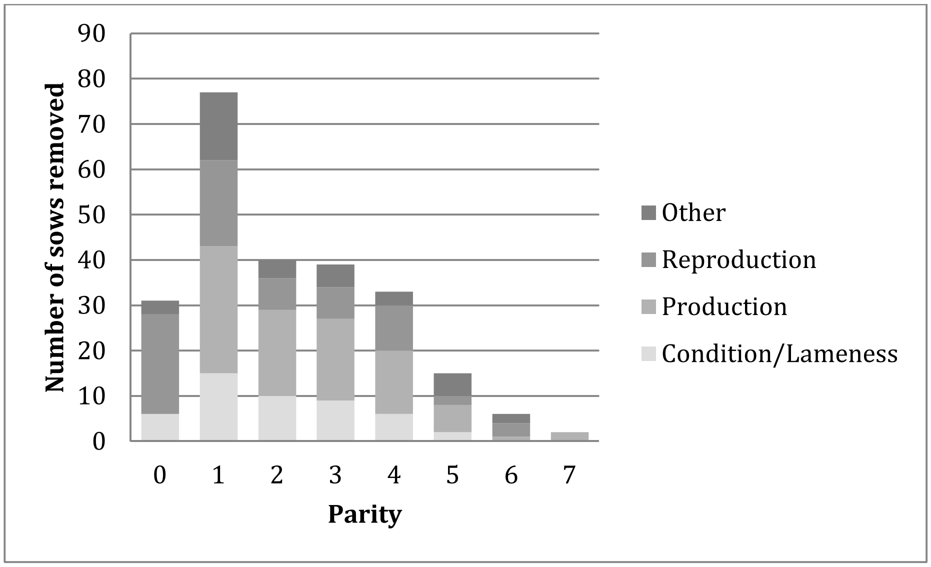

Figure 4.3: Involuntary removals by parity completed by reason

In agreement with literature results (Mote et al. 2008; Engblom 2008), the number of sows removed for reproductive failure and condition/lameness declined with increasing parity (Figure 4.3). This farm retains approximately 20% more gilts at selection than are needed to meet its replacement target. After involuntary culls prior to first farrowing (shown in Figure 4.3), a further voluntary cull was made based on index and conformation.

4.4 First and Second Parity Lactation Feed Delivery

A total of 273 sows had lactation feed intake records for both first and second parity. The phenotypic correlation between first and second parity lactation feed delivery was only 0.28 overall and ranged from 0.22 for Landrace to 0.45 for Yorkshire-H (Table 4.6). Hermesch et al. (2007) found a genetic correlation of 0.45 between first and second parity lactation feed intake and concluded that lactation intake in parity 1 is a different trait than lactation intake in later parities. This data appears to support the conclusion of Hermesch. A sow's first parity lactation is a period of major adjustment to farrowing, nursing a litter and receiving more feed than at any previous time in their lives and it may be that management factors around the farrowing period have a larger effect on lactation feed intake than any underlying genetic factors of the sow herself.

Table 4.6: Phenotypic Correlations between lactation feed intake in parity 1 and parity 2. (P value in parentheses)

	Overall	Landrace	Yorkshire-A	Yorkshire-H
Correlation	**0.28 (<0.01)**	**0.22 (<0.05)**	**0.35 (<0.01)**	**0.45 (<0.01)**

4.5 Transient Reductions in Lactation Feed Delivery

As a standardized means of identifying transient reductions in feed delivery for each genetic line and parity group, a regression model was constructed to predict daily feed intake for each genetic line and parity. The model used the daily lactation feed intake data and included the linear, quadratic and cubic effects of day, number and weight of pigs weaned and the linear and quadratic effect of the daily maximum temperatures recorded for each farrowing room. Tables 4.7 and 4.8 show the coefficients of the prediction model for each genetic line and parity, as well as the model r^2 and residual standard deviation for each breed and parity group. Only significant effects were included in each model (P<0.05). Figures 4.4 through 4.6 show the predicted and average feed delivery by day of lactation for each genetic line and parity.

A transient reduction in feed delivery was defined as a decrease in intake for two or more consecutive days of greater than 1.6 times the residual standard deviation of the prediction equation for the breed and parity group.

Litter weaning weight showed a significant positive effect on predicted lactation feed delivery in all breed and parity groups, while number of pigs weaned showed a small but significant negative effect on lactation feed delivery in 5 out of 6 (except for parity 2 Landrace) breed and parity groups. The linear and quadratic effect of maximum daily temperature showed variable effects on lactation feed delivery.

Table 4.7: Coefficients of a model to predict parity 1 lactation feed delivery

	Landrace	YO-A	YO-H
Intercept	1.154	1.22	1.15
Day	1.16	1.12	1.19
Day * Day	-0.059	-0.056	-0.063
Day * Day * Day	0.001	0.001	0.001
Wean weight	0.018	0.016	0.013
Pigs weaned	-0.096	-0.069	-0.082
Temperature	-	-0.069	-
Temp. * Temp.	-	-	-0.019
Model r^2	0.56	0.55	0.49
Residual Standard Deviation (RSD) (kg)	1.75	1.78	1.85
RSD * 1.6 (kg)	2.80	2.85	2.96

Table 4.8: Coefficients of a model to predict parity 2 lactation feed delivery

	Landrace	YO-A	YO-H
Intercept	0.66	0.00	0.39
Day	1.64	1.98	1.87
Day * Day	-0.010	-0.128	-0.125
Day * Day * Day	0.002	0.003	0.003
Wean weight	0.0199	0.014	0.031
Pigs weaned	-	-0.092	-0.177
Temperature	0.111	0.029	-
Temp. * Temp.	-0.013	-	-
Model r^2	0.54	0.63	0.53
Residual Standard Deviation (RSD) (kg)	2.06	1.87	2.08
RSD * 1.6 (kg)	3.30	3.00	3.33

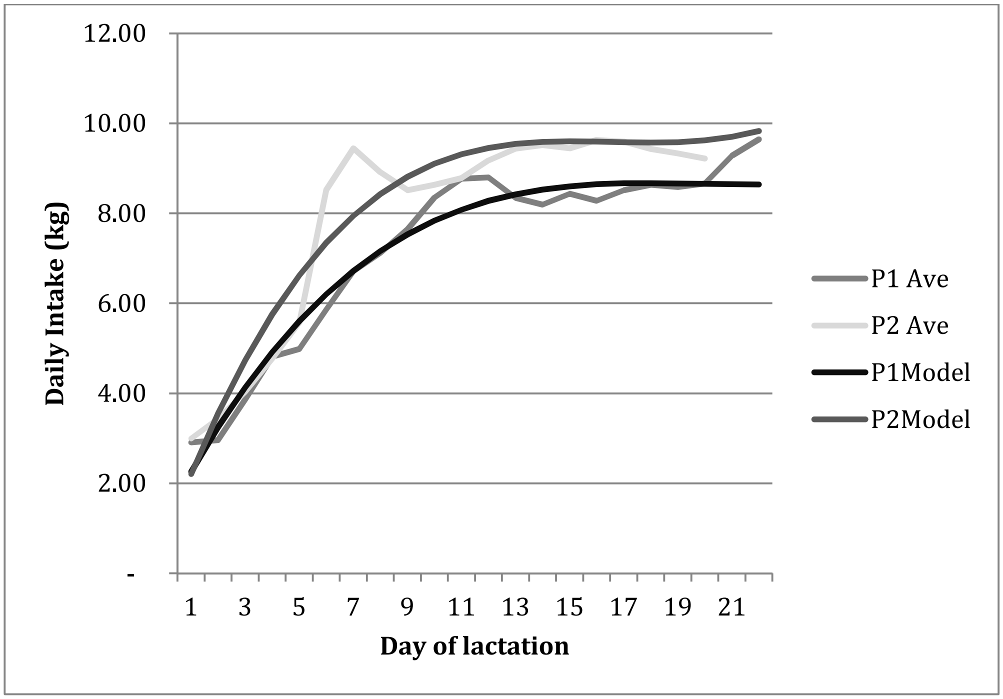

Figure 4.4: Average and predicted daily feed delivery for Landrace sows.

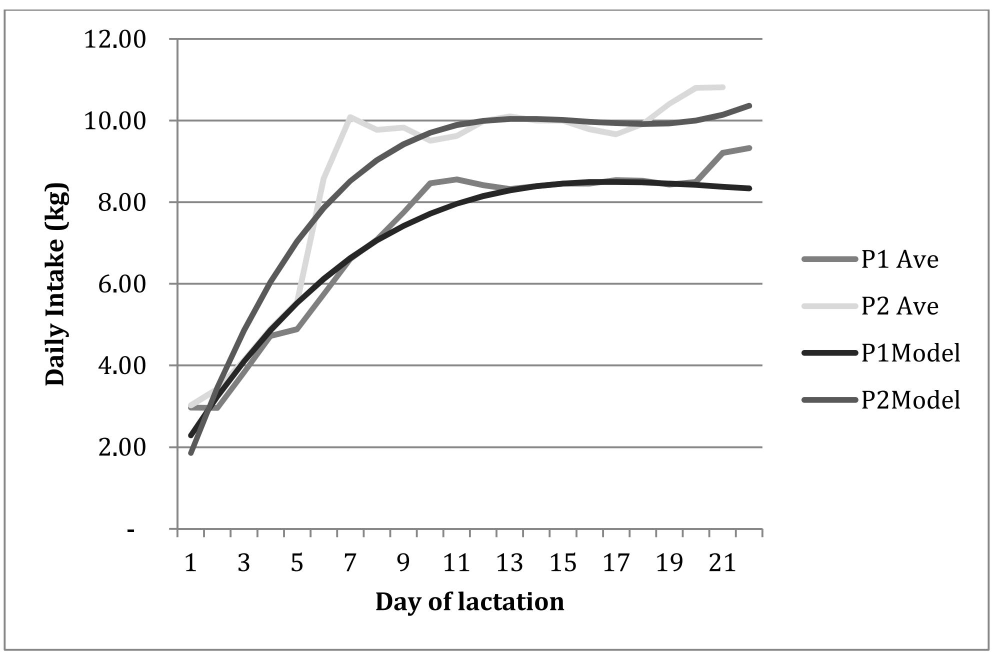

Figure 4.5: Average and predicted daily feed delivery for Yorkshire-A sows.

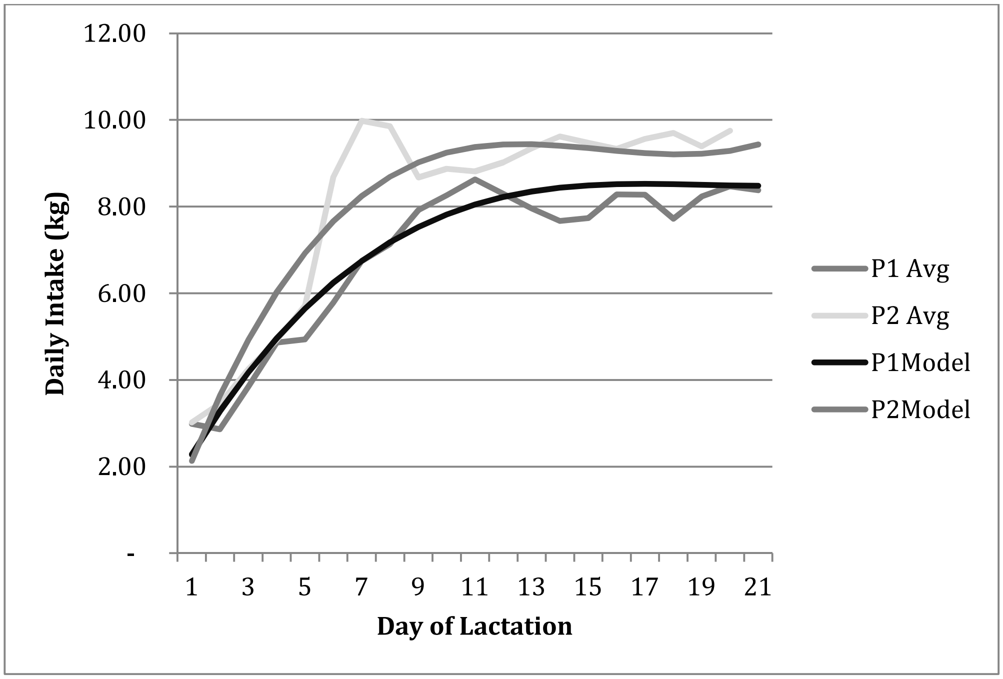

Figure 4.6: Average and predicted daily feed delivery for Yorkshire-H sows.

4.6 Lactation Feed Delivery and the Subsequent Litter.

Logistic Regression (Proc Logistic, SAS 9.2) was used to estimate the effects of a unit increase in daily lactation feed delivery on the successful completion of a subsequent litter. The results are shown in Table 4.9. Parity groups were modeled separately and breed group was included in the model as a fixed effect. Contemporary group, defined as either month or calendar quarter of farrowing were considered as potential random effects. Neither definition was significant and contemporary group was not included in the final model. A 1 kg per day increase in average daily feed delivery in the first lactation increased the odds of a completing a second litter by 32% (95% C.I. 1.06 – 1.65, $P < 0.05$). This value is in agreement with Anil et al. (2006) who found a 30% decrease in the odds of removal from the herd prior to the next litter from a one kg increase in average daily lactation feed intake. An almost identical result was found for feed delivery in parity 2 where a 1 kg per day increase increased the odds of a subsequent litter by 31% (95% C.I. 1.02 – 1.68, $P<0.05$). There was also a tendency for increased average daily feed delivery in the first lactation to reduce the odds of an extended weaning to conception interval (odds ratio = 0.73, P=0.08). No such effect was found for second parity lactation feed delivery (P = 0.36).

A linear mixed model (Proc Mixed, SAS 9.2) was used to estimate the effects of the lactation feed delivery variables of increased delivery, one or more days of zero delivery or one or more transient drops in delivery on total piglets born in the subsequent litter. Breed group of the sow was considered a fixed effect. Parity groups 1 and 2 were modeled separately. Contemporary group, defined as either month or calendar quarter of farrowing were considered separately as random effects, however, neither were significant and neither were included in the final model. The results are shown in Table 4.10. A 1 kg increase in average daily feed delivery in the first lactation resulted in an increase of 0.64 total born pigs in the next litter ($P<0.05$), while a 1 kg increase in daily feed delivery in second lactation had no effect on number of pigs born in the subsequent litter (P=0.69).

The binary independent variables of one or more days of zero feed delivery or one or more drops in delivery were tested for their effects on successful occurrence of the next litter, odds of an extended weaning to conception interval, and total born in the next litter (Tables 4.9 and 4.10). One or more days of zero delivery in parity 2 had a significant effect on parity 3 litter size of -1.38 pigs ($P<0.05$). Contrary to expectations, there was a tendency for a drop in delivery in parity 2 to improve the odds of a third litter with an odds ratio of 1.6 (P=0.08). All other effects tested were not significant. It is important to note that the sows in this study were fed using self feeders holding approximately 12 kg of feed, and that feed was recorded as delivered to the feeder rather than as consumed by the sow. It is likely that this masked some of the daily variations in lactation feed intake.

Table 4.9: Logistic regression results. Feed delivery and feed delivery patterns and subsequent performance.

	Odds Ratio Estimate	95% Confidence Interval	P Value
Average daily lactation feed delivery + 1 kg			
P1 intake vs. subsequent litter	**1.32**	**1.06 – 1.65**	**0.01**
P2 intake vs. subsequent litter	**1.31**	**1.02 – 1.68**	**0.04**
P1 intake vs. extended WCI	0.73	0.51 – 1.04	0.08
P2 intake vs. extended WCI	1.44	0.65 – 3.19	0.37
1 or more lactation feed delivery drops			
P1 drop vs. subsequent litter	1.16	0.77 – 1.74	0.47
P2 drop vs. subsequent litter	1.61	0.94 – 2.73	0.08
P1 drop vs. extended WCI	1.26	0.62 – 2.55	0.53
P2 drop vs. extended WCI	1.28	0.24 – 6.96	0.78
1 or more lactation feed delivery zero days			
P1 zero day vs. subsequent litter	1.08	0.72 – 1.61	0.72
P2 zero day vs. subsequent litter	1.50	0.85 – 2.62	0.16
P1 zero day vs. extended WCI	1.13	0.57 – 2.23	0.53
P2 zero day vs. extended WCI	0.54	0.12 – 2.53	0.43

(WCI – Weaning to conception Interval) (N=350 parity 1 and 193 parity 2 records)

Table 4.10: Mixed model results. Lactation feed delivery and intake patterns and next litter total born.

	Litters	Estimate	S.E.M.	P Value
Lactation feed delivery vs. next litter total born				
Parity 1	350	**0.64**	**0.27**	**0.02**
Parity 2	193	0.11	0.28	0.69
One or more intake drops vs. next litter total born				
Parity 1	350	-0.18	0.43	0.68
Parity 2	193	-0.35	0.58	0.55
One or more zero days vs. next litter total born				
Parity 1	350	-0.43	0.42	0.31
Parity 2	193	**-1.38**	**0.62**	**0.03**

4.7 Lactation Feed Delivery and Lifetime Performance

A 1 kg increase in daily feed delivery in first lactation resulted in longer productive life (+33.4 days, P=0.01), additional litters raised (+0.24 litters, P=0.01) and more lifetime piglets weaned (+2.67 pigs, P<0.01). Similarly a 1 kg increase in daily feed delivery in the second lactation increased productive life (+32.9 days, P<0.01), parities completed (+0.2 litters, P < 0.05) and pigs weaned (+2.49 pigs, P<0.05). These results are shown in Table 4.11.

Table 4.11: Effect of additional daily lactation feed delivery on lifetime performance

	Estimate	Std. Error	P Value
Parity 1 intake			
Age at removal (days)	**+33.4**	**12.97**	**0.01**
Parities completed	**+0.24**	**0.09**	**0.01**
Lifetime pigs weaned	**+2.67**	**1.02**	**< 0.01**
Parity 2 intake			
Age at removal (days)	**+ 32.9**	**12.46**	**0.01**
Parities completed	**+ 0.20**	**0.09**	**0.02**
Lifetime pigs weaned	**+ 2.49**	**1.03**	**0.02**

For the binary response variables of stayability to parity 3 or parity 4, increased lactation feed delivery also had a positive effect (Table 4.12). A 1 kg increase in daily feed delivery in first lactation improved the odds of completing parity 4 (odds ratio 1.48, P<0.01) and tended to improve the odds of completing parity 3 (odds ratio 1.22, P=0.07). A 1 kg increase in daily lactation feed delivery in second parity increased the odds of successful completion of parity 3 and 4 (odds ratios of 1.31 and 1.41 respectively, P<0.05).

Table 4.12: Effect of additional daily lactation feed delivery on stayability to parity 3 or 4.

	Odds Ratio	95% C.I.	P Value
Parity 1 intake			
Completion of parity 3	1.22	0.98 – 1.52	0.07
Completion of parity 4	**1.48**	**1.14 – 1.92**	**<0.01**
Parity 2 intake			
Completion of parity 3	**1.31**	**1.01 – 1.69**	**0.04**
Completion of parity 4	**1.41**	**1.08 – 1.83**	**<0.01**

4.8 Growth Phenotypes and Lactation Feed Delivery

At an off-test age of approximately 146 days, gilts were weighed and estimates of backfat and loin muscle depth were taken by ultrasound. Growth rate (expressed as number of days), backfat and loin muscle depth were adjusted to a standard weight of 100 kg using adjustment factors developed by the Canadian Center for Swine Improvement (unpublished). Daily feed intake in the growth period was adjusted for start weight and number of days on the FIRE feeders using the methods described earlier herein. Correlations were calculated between the growth and carcass traits measured and average daily lactation feed delivery. Correlations were calculated for parity 1 and parity 2 lactation delivery separately and both within and across breed groups (Table 4.13).

Within or across breeds, there were no significant correlations between growth rate, backfat, loin muscle depth or growth period feed intake and subsequent lactation feed delivery in first parity. For parity 2 lactation feed delivery there was a significant favorable correlation of -0.25 ($P<0.05$) between days to 100 kg and lactation feed delivery and a correlation of -0.23 ($P<0.05$) between ultrasound loin muscle depth and lactation feed delivery, both for the Yorkshire-A line only. The favorable correlation between growth rate in the growing period and lactation intake has been reported by other authors (Hermesch et al. 2010; Kerr and Cameron 1996c; Bunter et al. 2010b), usually using growth EBV rather than phenotype.

Table 4.13 : Correlations of growth period phenotypes with lactation feed delivery. Estimate (P value)

	Across Lines correlation	Within Landrace	Within YO-A	Within YO-H
Growth rate				
Parity 1	-0.06 (0.19)	-0.09 (0.18)	0.03 (0.68)	-0.16 (0.13)
Parity 2	0.04 (0.48)	0.02 (0.79)	**-0.25 (0.01)**	0.15 (0.31)
Backfat				
Parity 1	-0.02 (0.61)	-0.03 (0.63)	-0.03 (0.69)	0.03 (0.80)
Parity 2	0.03 (0.67)	-0.04 (0.68)	-0.13 (0.22)	-0.19 (0.22)
Lean depth				
Parity 1	-0.05 (0.25)	-0.07 (0.29)	-0.01 (0.85)	-0.06 (0.56)
Parity 2	0.08 (0.18)	0.01 (0.93)	**-0.23 (0.03)**	-0.21 (0.18)
Growth period feed intake				
Parity 1	0.06 (0.18)	0.08 (0.24)	0.06 (0.39)	-0.05 (0.66)
Parity 2	0.10 (0.11)	-0.03 (0.78)	0.02 (0.83)	-0.17 (0.28)

(N = 478 Parity 1 animals, 257 Parity 2 animals)

4.9 Estimation of Genetic Parameters and Estimated Breeding Values

4.8.1 Estimation of Genetic Parameters

Genetic parameters for each breed group were estimated using ASReml 3.0 (Gilmour et al. 2009). For the growth period traits of backfat and loin depth, data was pre-adjusted for off test weight using the adjustment factors of Canadian Center for Swine Improvement (unpublished). The model for growth rate included linear and quadratic effects of off test weight as linear covariates. The models for growth rate, backfat, loin depth, feed intake and feed conversion include fixed effects of sex and contemporary group, defined as calendar quarter within year and herd. Additive genetic effect of animal and permanent environment effect of litter were included as random effects.

Maternal traits evaluated included litter size, weaning to conception interval and litter weaning weight. Litter size was defined as piglets alive at day 2 and weighing 800 grams or more at birth. Weaning to conception interval was evaluated for the interval following parity 1 only.

Litter weaning weight was pre-adjusted using a mixed model (Proc Mixed, SAS 9.2) for the effects of average birth weight of the litter as fostered. The model for litter weaning weight included fixed effects of parity class of the sow, breed of the litter (purebred vs. crossbred) and contemporary group, defined as calendar quarter of farrowing within year and herd. Linear covariates were number of days in lactation and number of pigs weaned. Random effects were the additive genetic effect of animal (dam) and the permanent effect of dam to account for repeated records.

The model for litter size included fixed effects of parity class, breed of litter (purebred or crossbred) and contemporary group, defined as above, and random effects of additive genetic effect of animal and permanent effect of dam. The model for weaning to conception interval included the fixed effects of litter breed (purebred or crossbred) and contemporary group, defined as above and linear covariates of number weaned and number of lactation days. There were no repeated records for this trait since it was defined to include the interval following first parity only.

Tables 4.14 and 4.15 contain the estimates of variance components and heritability for growth period traits in Landrace and Yorkshire pigs respectively while Tables 4.16 and 4.17 show the estimates for litter traits for the two breed groups. For growth period traits, the heritability estimates for average daily gain, daily feed intake and backfat are similar to the mean of estimates reviewed by Clutter and Brascamp (1998) while the estimates for feed conversion are at or below the low end of the range reviewed in the same paper. Since the estimates for daily feed intake are similar to average literature values, it is likely that the low estimate for feed conversion is due to errors in measurement of gain during the relatively short period that pigs spent on the feed intake recording equipment.

Table 4.14: Variance component estimates for growth period traits in Landrace pigs

	Variance due to				Ratios			
	Animal	Litter	Residual	Total	h^2 *	SEM	c^2 **	SEM
Gain	1348	558	2202	4108	0.33	0.01	0.14	0.004
Feed intake	0.019	0.007	0.050	0.076	0.25	0.01	0.09	0.003
Feed conversion	0.008	0.003	0.044	0.055	0.15	0.03	0.05	0.018
Backfat	1.242	0.212	1.415	2.869	0.43	0.01	0.07	0.003
Loin depth	7.88	1.83	13.39	23.10	0.34	0.01	0.08	0.003

* h^2: heritability ** c^2: litter effect
Trait units are: Gain (g/day); Feed Intake (kg/day); Feed conversion (kg/kg), backfat(mm); Loin depth (mm).

Table 4.15: Variance component estimates for growth period traits in Yorkshire pigs

	Variance due to				Ratios			
	Animal	Litter	Residual	Total	h^2 *	SEM	c^2 **	SEM
Gain	1490	589	2213	4293	0.35	0.01	0.14	0.004
Feed intake	0.026	0.004	0.065	0.095	0.27	0.03	0.05	0.017
Feed conversion	0.004	0.003	0.047	0.055	0.08	0.02	0.05	0.018
Backfat	1.28	0.27	1.64	3.20	0.40	0.01	0.09	0.003
Loin depth	6.59	1.94	12.03	20.56	0.32	0.01	0.03	0.003

* h^2: heritability ** c^2: litter effect
Trait units are: Gain (g/day); Feed Intake (kg/day); Feed conversion (kg/kg), backfat(mm); Loin depth (mm).

For litter traits, the estimates of heritability for litter size and weaning weight are similar to the mean of estimates reviewed by Rothschild and Bidanel (1998) while the estimates for weaning to conception interval were toward the lower end of the range of estimates reviewed in the same paper. The EBV data set reported here includes a large number of herds with varying management practices, including some that routinely use gonadotropin treatments on weaned first parity sows and some that practice a skip-heat program on these young sows. Such management practices may mask a portion of the genetic variation in weaning to conception interval. Also, this study excluded sows with weaning to conception intervals longer than 30 days from the data set for estimation of genetic parameters. Some literature reports have included intervals of up to 90 days for weaning to conception interval, thus including sows that have conceived on second or third estrus after weaning. Some breed differences in heritability were observed with Yorkshire having a higher heritability for weaning to conception interval (0.20 vs. 0.16) and Landrace having higher heritability for litter weaning weight (0.16 vs. 0.11).

Genetic and phenotypic correlations between growth traits are shown in Tables 4.18 and 4.19 for the Landrace and Yorkshire breeds respectively. In agreement with literature values (Clutter and Brascamp 08), genetic and phenotypic correlations between daily gain and feed intake and between backfat and feed intake were strongly positive. Genetic and phenotypic correlations between daily gain and feed conversion and backfat and feed conversion showed moderate negative (favorable) values. Correlations between loin muscle depth measurements and feed intake or feed conversion were near zero. Correlations between feed intake and feed conversion were not estimated since the two variables use the same feed intake value.

Table 4.16: Variance component estimates for maternal traits for Landrace pigs.

	Variance due to				**Ratios**			
	Animal	**Dam**	**Residual**	**Total**	**h^2 [2]**	**S.E.M.**	**c^2 [3]**	**S.E.M.**
Litter size	1.03	0.75	8.46	10.23	0.10	0.006	0.07	0.006
WCI [1]	0.54		2.87	3.42	0.16	0.011		
Wean weight	7.68	2.71	36.60	46.99	0.16	0.019	0.06	0.023

[1] WCI: weaning to conception interval. [2] h^2: heritability. [3] c^2 : permanent effect of dam. Trait units are Litter size (pigs); WCI (days); Wean weight (kg/litter).

Table 4.17: Variance component estimates for maternal traits for Yorkshire pigs.

	Variance due to				Ratios			
	Animal	**Dam**	**Residual**	**Total**	**h^2 [2]**	**S.E.M.**	**c^2 [3]**	**S.E.M.**
Litter size	1.14	0.77	8.44	10.34	0.11	0.004	0.07	0.003
WCI [1]	0.85		3.37	4.23	0.20	0.010		
Wean weight	8.66	4.63	64.36	77.64	0.11	0.011	0.06	0.009

[1] WCI: weaning to conception interval. [2] h^2: heritability. [3] c^2 : permanent effect of dam. Trait units are Litter size (pigs); WCI (days); Wean weight (kg/litter).

Genetic and phenotypic correlations between maternal traits of litter size, weaning to conception interval and litter weaning weight are shown in Tables 4.20 and 4.21 for Landrace and Yorkshire breeds respectively. The genetic correlations between litter size and litter weaning weight were moderate and the phenotypic correlations near zero in this data set in contrast to the estimates reviewed by Rothschild and Bidanel (1998) where strongly positive correlations of 0.61 (genetic) and 0.53 (phenotypic) were found. These differences are probably due to the different models used. In this data set, both starting weight of the litter as raised and number of pigs weaned in the litter were used as covariates, effectively removing the effects of different average birth weights in the fostered litter and expressing the weaning weight EBV as a per piglet weight. Model details for different estimates were not reported in the review of Rothschild and Bidanel (1998). Genetic correlations between litter weaning weight and weaning to conception interval were strongly negative (favorable) at -0.55 for Landrace and -0.42 for Yorkshire, while phenotypic correlations were more modest but still negative at -0.14 and -0.11 for Landrace and Yorkshire respectively. This finding is in general agreement with Tholen et al. (1996) who estimated this correlation for each parity separately and found negative genetic correlations of -0.09 and -0.46 in parity 1 and 2 respectively but a positive correlation of 0.23 in parity 3 sows. Tholen also found modest phenotypic correlations of -0.04 in parity 1 and 2 and +0.02 in parity 3.

Table 4.18: Genetic and phenotypic correlations between growth traits: Landrace

	Gain	Daily Feed Intake	Feed Conversion	Backfat	Loin Depth
Gain	-	0.41	-0.21	0.29	0.07
Daily feed intake	0.32	-	-	0.47	-0.22
Feed conversion	-0.25	-	-	0.19	-0.09
Backfat	0.52	0.32	0.11	-	0.09
Loin depth	0.07	-0.10	0.01	-0.25	-

(Genetic correlations above diagonal, phenotypic below)

Table 4.19: Genetic and phenotypic correlations between growth traits: Yorkshire

	Average Daily Gain	Daily Feed Intake	Feed Conversion	Backfat	Loin Depth
Gain	-	0.51	-0.17	0.41	-0.06
Daily feed intake	0.39	-	-	0.44	-0.15
Feed conversion	-0.25	-	-	0.21	0.0
Backfat	0.29	0.27	0.07	-	0.12
Loin depth	-0.01	-0.05	0.02	0.16	-

(Genetic correlations above diagonal, phenotypic below)

Table 4.20: Genetic and phenotypic correlations between maternal traits: Landrace

	Number Born	Litter Wean Weight	Weaning to conception Interval
Number born	-	0.35	-0.39
Litter wean weight	0.08	-	-0.55
WCI *	0.02	-0.14	-

(Genetic correlations above diagonal, phenotypic below) * WCI: Weaning to conception interval

Table 4.21: Genetic and phenotypic correlations between maternal traits: Yorkshire

	Number Born	Litter Wean Weight	Weaning to conception Interval
Number born	-	0.22	-0.34
Litter wean weight	-0.01	-	-0.42
Weaning to conception interval	-0.01	-0.11	-

(Genetic correlations above diagonal, phenotypic below)

4.10 Estimated Breeding Values and Lactation Feed Delivery

Using the above genetic parameters, and data from the entire breeding company population, estimated breeding values (EBV's) were computed for five growth period and three maternal traits, and correlations calculated between each EBV and lactation feed delivery (Table 4.22). There were no significant correlations between growth period EBV and lactation feed delivery in parity 1. Lactation feed delivery in parity 2 sows showed significant correlations with EBV for growth rate, daily feed intake, feed conversion and number born. The correlations with growth rate, feed conversion and number born were favorable while the correlation with daily feed intake was not. Other authors (Hermesch 2010; Kerr and Cameron 1996c; Bunter et al. 2010) have found growth rate EBV to be positively correlated with lactation feed delivery and selection for lower feed intake in the growing period to negatively affect lactation feed delivery (Kerr and Cameron 1995, 1996a,b,c).

Table 4.22: Correlations between EBV and lactation feed delivery in parity 1 and 2

	Parity 1		Parity 2	
EBV	**Correlation**	**P Value**	**Correlation**	**P Value**
Gain	0.0	0.98	0.24	<0.01
Daily feed intake	-0.01	0.86	0.19	<0.01
Feed conversion	0.01	0.89	-0.21	<0.01
Backfat	-0.02	0.72	-0.07	0.23
Loin muscle depth	-0.06	0.18	0.02	0.74
Number born/litter	0.00	0.97	0.22	<0.01
Weaning to conception interval	-0.07	0.13	-0.08	0.17
Litter wean weight	0.06	0.21	-0.08	0.19

Discovering the relationship between daily feed intake in the growth period and in lactation was a major objective of this study. While there were no significant relationships between growth period EBV and parity 1 lactation feed delivery, the significant relationships with parity 2 lactation feed delivery were expected based on literature results (Bunter et al. 2007; Bergsma et al. 2013; Hermesch et al. 2010; Bunter et al. 2010b).

4.11 Growth Period and Sow Productivity EBV

Table 4.23 shows the correlations between growth period and sow productivity EBV. Correlations between growth period and maternal EBV were generally favorable, with the exception of the EBV for daily feed intake in the growth period. Litter size had highly significant correlations with all the growth period EBV. Litter weaning weight was favorably correlated with daily gain and backfat measured in the growth period. Positive correlations between sow productivity traits and growth traits in the index might be expected to result in improved sow productivity and longevity from selection for growth. On the other hand, selection goals that result in reduced feed intake in the growing period may have negative effects on the maternal traits of weaning to conception interval, litter size and weaning weight, given the correlations between these EBV and that for daily feed intake in the growing period.

Table 4.23: Correlations between growth period and sow productivity EBV.

	Weaning to Conception Interval	Litter Size	Litter Wean Weight
Daily gain	-0.07 (0.09)	0.69 (<0.01)	0.16 (<0.01)
Feed conversion	0.12 (<0.01)	-0.47 (<0.01)	0.07 (0.13)
Daily feed intake	-0.08 (0.05)	0.29 (<0.01)	0.08 (0.06)
Back fat	-0.07 (0.11)	-0.28 (<0.01)	-0.23 (<0.01)
Loin depth	0.06 (0.18)	0.24 (<0.01)	0.05 (0.25)

Correlation (P Value) (Across breed results shown)

4.12 Predicting Sow Longevity

Sow longevity is generally considered to be a lowly heritable trait. Engblom (2008) found heritability estimates of 0.03 to 0.12 for sow longevity using survival analysis and linear models. Serenius and Stalder (2004) estimated heritability for sow productive life using proportional hazards (survival analysis) and linear models and found heritability estimates of 0.05 to 0.10 for linear models and higher estimates of 0.16 to 0.19 for survival analysis models. Besides being lowly heritable, sow longevity is particularly difficult to evaluate in a nucleus herd because of voluntary culling for genetic value (index). It would be useful if indicator traits could be found that would allow prediction of sow longevity based on traits that are expressed early in life, especially if they were expressed prior to selection, or in the first parity. In this data set we have three measures of the productive lifetime of the sow, age at removal, lifetime pigs weaned and lifetime parities. In addition, we have good phenotypic indicators of sow longevity in first and second lactation feed delivery.

A stepwise regression analysis (Proc Reg, SAS 9.2, SAS Institute) was performed using trait EBV for growth period traits (daily feed intake, growth rate, backfat, loin muscle depth) and sow productivity traits (weaning to conception interval, number alive at day 2 and litter weaning weight) to predict age at removal, lifetime litters and lifetime pigs weaned (Tables 4.24 to 4.26). Because the nucleus practice of culling on index would result in an autocorrelation, animals removed voluntarily for index reasons were excluded from this analysis. After this exclusion, there were 389 animals that had at least a first litter in the data set. A dummy variable for breed/line was created (1=Landrace, 2=Yorkshire-A, 3=Yorkshire-H) to enable the analysis to be carried out across breeds. Breed/line did not achieve the threshold significance level of 0.15 for entry into the model in any of the regression equations, indicating that the 3 genetic lines of this data set were not behaving differently in terms of factors affecting productive life.

For all three measurements of productive lifetime, the best single predictor variable was weaning to conception interval (P<0.01). A significant contribution was also made by weaning weight (P<0.05) and further non-significant contributions were added by daily feed intake in the growing period and litter size. The regression coefficients, model R squared and P value for each trait included are shown in Tables 4.24 through 4.26. Predictive value of the models as measured by model R squared were between 0.08 and 0.10 depending on the trait. These values are modest, but of the same magnitude as the heritability of sow longevity itself (Tholen et al. 1996; Serenius and Stalder 2004 and 2006).

Table 4.24: A regression model to predict age at removal from EBV:

	Estimate	Model r^2	Variable P Value
Intercept	618.78		
Weaning to conception interval	-22.90	0.055	<0.0001
Weaning weight	12.75	0.070	0.014
Daily feed intake	-240.6	0.075	0.14
Litter size	18.57	-0.081	0.11

Table 4.25: A regression to predict lifetime pigs weaned from EBV:

	Estimate	Model r^2	Variable P Value
Intercept	26.89		
Weaning to conception interval	-1.95	0.068	< 0.0001
Weaning weight	1.13	0.087	0.005
Daily feed intake	-19.11	0.092	0.14
Litter size	1.66	0.100	0.06

Table 4.26: A regression to predict lifetime parities from EBV:

	Estimate	Model r^2	Variable P Value
Intercept	2.64		
Weaning to conception interval	-0.175	0.06	<0.0001
Weaning weight	0.084	0.073	0.02
Daily feed intake	-1.80	0.079	0.13
Litter size	0.150	0.087	0.07

Coefficients for the sow productivity traits of weaning to conception interval, weaning weight and litter size show favorable relationships with longevity measures, while the EBV for daily feed intake in the growing period exhibits an unfavorable negative coefficient. Selection on reduced daily feed intake in the growing period appears to predict a negative effect on sow longevity.

5. CONCLUSIONS

The first question to be investigated by this research was to determine if, in agreement with literature results, lactation feed delivery affected future productivity measures such as weaning to conception interval, total born in the subsequent litter, stayability or length of productive life. This work has affirmed that feed delivery in lactation is clearly very important to sow longevity and productivity in this population. An increase of 1 kg in lactation feed delivery in the first or second parity improved odds of successful completion of the next litter by 32 and 31% respectively, a result almost identical to that found by Anil et al. (2006). A 1 kg increase in lactation feed delivery also improved stayability to parity 3 and parity 4, in agreement with the results of Knauer et al. (2010). Productive lifetime was improved by 0.2 to 0.24 additional litters and 2.49 to 2.67 additional pigs weaned. An increase of 1 kg in feed delivery in the first parity increased total born in parity 2 by 0.64 pigs/litter, in agreement with Eissen et al. (2003) and Koketsu and Dial (1996). An increase in lactation feed delivery also had a tendency to reduce the odds of an extended weaning to conception interval after parity 1, in agreement with several previously reported results (Anil et al. 2006; Young et al. 1991; Koketsu and Dial 1996).

Previous researchers (Anil et al. 2006; Schinkel et al. 2010) found that one or more days of feed refusal, or 2 or more consecutive days of reduction in feed delivery also affected future reproductive performance. This data set found minimal effects in this area, with only feed refusal of one or more days in parity 2 having a significant effect on parity 3 litter size of -1.38 pigs ($P<0.05$). All other effects tested were non-significant. This is likely due to the use of self feeders that hold at least a full day's feed intake and feed being measured as delivered rather than as consumed, masking true feed intake reduction or refusal events.

The second question to be investigated by this research was if feed intake of the gilt in the growing period predicted her subsequent feed delivery in lactation. In this data set, feed intake as measured by automated feed intake recording equipment for a 17 day period post selection was not related to feed delivery in lactation. Other research results on this question have been variable. Bunter et al. (2010) found a phenotypic correlation of only 0.07 and 0.10 between feed intake in a post selection growing period and lactation feed intake in parity 1 and parity 2 respectively, and in a different data set, Bunter et al. (2007) reported phenotypic correlations between feed intake in the growing period and in lactation of 0.05 and 0.04 in two different maternal lines. Rauw et al. (2008), on the other hand, found a phenotypic correlation of 0.50 between feed intake in the growing period and in lactation in the mouse.

A third question was if there were relationships between other growing period phenotypes measured and lactation feed delivery. In this data set, none of the other phenotypes recorded in the growing period (daily gain, backfat, loin depth) showed significant relationships with lactation feed delivery in parity 1. For one of the 3 genetic lines (Yorkshire-A), there were significant correlations between growth rate and lactation feed delivery and between loin muscle depth and lactation feed delivery in parity 2. Some authors (Kerr and Cameron 1996c; Bunter et al. 2010) have reported positive correlations between daily gain and lactation feed intake. Most previous researchers who have found significant results however, have reported significant correlations at the additive genetic level rather than phenotypic correlations.

The fourth question to be investigated by this research was the relationship between estimated breeding values for traits expressed in the growth period and lactation feed delivery. Estimated breeding values for growing period traits of growth rate, feed conversion and feed intake were more accurate indicators of lactation feed delivery than were growing period phenotypes, also in agreement with previous investigators. There were favorable correlations between EBV for growth rate, feed conversion and litter size and lactation feed delivery in parity 2, as well as an unfavorable correlation between feed intake EBV and parity 2 lactation feed delivery. Characterizing the relationship between feed intake in the growing period and in lactation was a major objective of this study, and while phenotypic measurements of growth period traits were not useful in predicting lactation feed delivery, significant correlations with the EBV for growth period traits of feed intake, feed conversion and growth rates were found, at least for lactation feed delivery in parity 2. The positive (unfavorable) correlation of 0.19 found between the EBV for growth period feed intake and parity 2 lactation feed delivery was highly significant ($P<0.01$) but moderate in magnitude.

Estimates of heritability and genetic and phenotypic correlations between traits in this population are in general agreement with literature values with some exceptions. The estimate for heritability of feed conversion in this data set is lower than most literature values, however the estimate for feed intake using the same feed intake data is near the average as reviewed by Clutter and Brascamp (1998). Since feed intake in this data set appears to have similar genetic variation as that reported in other studies, it is believed that inaccuracy in measuring weight gain over a short period of time on the feed intake recording equipment is most likely responsible for the low value for feed conversion.

The heritability estimates for weaning to conception interval in this data set were near the lower end of litter estimates as reviewed by Rothschild and Bidanel (1998). It is believed that this is due to differences in definition of the trait. While the review by Rothschild and Bidanel (1998) did not report the details of each estimate, the population of this study included some farms that routinely administer gonadotropins to first parity weaned sows and other herds that practice a skip heat program on these first parity sows. In this data set, weaning to conception interval was limited to 30 days post weaning while some other papers have allowed much longer weaning to conception intervals, including repeat breeders. The heritability estimates in this study for litter size and litter weaning weight were within the range of literature values as reviewed by Rothschild and Bidanel (1998), but the genetic correlation between the two traits was lower than literature estimates. This is also most likely due to the models chosen for the traits. Litter weaning weight in this data set was adjusted for both the average birth weight of pigs in the fostered litter, and for the number of pigs weaned. The EBV for litter size in this data set used pigs alive at day two after birth while litter size EBV are commonly calculated using total born per litter or born alive.

With only 478 parity 1 and 257 parity 2 lactation feed delivery records and three genetic lines, there are not enough records in this data set to provide a reliable estimate genetic of parameters or compute EBV for lactation feed delivery. However, given the importance of lactation feed delivery to future productivity and sow longevity, and the positive correlation found between feed intake EBV from the growing period and lactation feed delivery, it is recommended that lactation feed delivery be recorded directly and included in the selection goal, possibly in conjunction with weight and backfat loss in lactation. Further work needs to be done to estimate genetic variation in lactation feed delivery in these maternal lines. Literature estimates of heritability of lactation feed intake are few and have a wide range of values. Bunter et al. (2009a) estimated heritability of lactation feed intake at 0.16 while Bergsma et al. (2008) found values of 0.20 to 0.39 in 4 different populations. With further knowledge of the heritability of lactation feed intake, it may be possible to select in opposite directions for feed intake in the growing period and in lactation. On the other hand, if the genetic correlation between the two traits in these populations proves to be much higher than the phenotypic correlation of 0.19 found here, a selection strategy that includes strong selection on feed intake in the growth period may not be appropriate.

The phenotypic correlation between lactation feed delivery in parity 1 and 2 was low, at 0.28 overall. Correlations within genetic lines ranged from 0.22 for Landrace to 0.45 for Yorkshire-H. This result was unexpected. However, the low correlation between parities and the differing correlations with growth period EBV support the conclusion of Hermesch et al. (2007) that lactation feed intake in parity 1 is a different trait than in parity 2. This result will have to be considered when estimating genetic parameters for lactation feed intake.

Overall, there is strong evidence that feed delivery in first and second parity lactations is strongly related to future productivity and length of productive life in sows. EBV for growth period traits appears to be correlated with lactation feed delivery, at least in second parity. There is evidence that selection for reduced feed intake in the growing period, whether directly as a selection goal, or indirectly as a result of selection for feed conversion, residual feed intake or leanness may result in reduced lactation feed delivery and subsequent reduction of lifetime productivity. It is recommended that selection for feed efficiency, feed intake or residual feed intake in maternal lines be balanced by selection for improved lactation feed delivery, or perhaps an index of lactation feed delivery and sow weight and backfat loss in lactation.

The last question posed for investigation by this project was regarding the possibility of developing an index of predictor traits for sow longevity that could be measured early in life. Dairy cattle breeders have found that somatic cell count, fertility and some conformation traits are predictive of longevity in dairy cattle (Harris and Montgomerie 2007; Van Raden et al. 2004; Mrode et al. 2000; Miglior and Sewalem 2009). The stepwise regression models shown in this thesis used EBV for maternal and growing period traits to predict measures of longevity including length of productive life, litters completed and lifetime number of pigs weaned. The ebv for weaning to conception interval was the most significant single predictor of lifetime productivity ($P<0.01$) while litter weaning weight was next most important ($P<0.05$). Modest, non-significant contributions were added by EBV for daily feed intake in the growing period and litter size. Overall, r^2 values for the regressions were 0.08 to 0.10 depending on the longevity trait chosen. While modest, the R squared value is within the range of literature estimates for heritability of sow longevity itself. It is possible that a future EBV for lactation feed intake, or some measure of lactation efficiency may be valuable as an additional predictor of length of productive life. Further research is needed to identify genetic variation in lactation feed intake and any genetic relationship to longevity.

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Appendix A: Ration Specifications and Formulae

Table A1: Ration nutrient specifications:

	Lactation	Gestation	(FIRE Feeder)
ME (kcal/kg)	3350	3015	3115
NE (kcal/kg)	2450	2325	2380
Crude protein (%)	21.6	13.1	16.25
Salt (%)	0.39	0.46	0.41
Lysine (%)	1.17	0.67	0.97
Isoleucine (%)	0.85	0.49	0.61
Valine (%)	0.97	0.63	0.80
Crude fat (%)	4.6	2.23	6.06
Crude fiber (%)	4.26	4.3	5.0
Calcium (%)	0.9	0.9	0.79
Phosphorus (%)	0.67	0.64	0.51
Potassium (%)	0.63	0.57	0.64
Manganese (mg/kg)	95	81	74
Zinc (mg/kg)	185.	180	180
Iron (mg/kg)	291.	316	284.5
Copper (mg/kg)	23.5	24.4	24.2
Magnesium (%)	0.22	0.14	0.17
Selenium (mg/kg)	0.58	0.45	0.48
Sodium (%)	0.20	0.20	0.19
Chloride (%)	0.44	0.41	0.43
Vitamin A (KIU/kg)	12.5	12.5	12.5
Vitamin D (KIU/kg)	1.5	1.5	1.5
Biotin (mg/kg)	0.65	0.55	0.80

Table A2: Major ingredients of the lactation ration by date (kg/tonne)

Date	Wheat	Corn DDGS	Soybean Meal	Barley	Canola Meal	Peas	Hulless Barley
11-Jun-10	491	150	123	0	105	65	15
10-Sep-10	491	150	123	0	105	65	15
12-Oct-10	491	150	123	0	105	65	15
1-Nov-10	485	150	124	0	110	65	15
6-Dec-10	498	0	135	123	110	65	0
21-Jan-11	375	0	119	32	120	82	200
2-Feb-11	376	0	119	32	120	80	200
17-Mar-11	499	0	128	110	105	85	0

Table A3: Major ingredients of the gestation ration by date (kg/tonne)

Date	Wheat	Corn DDGS	Soybean Meal	Barley	Canola Meal	Peas	Hulless Barley
31-May-10		144	25	620	105	68	
06-Dec-10	321		25	443	100	68	
10-Jan-11	227		25	448	32	100	124
03-Mar-11	228		28	594		105	
08-Apr-11	187		20	624	20	105	
14-Oct-11	499		20	300	103	38	

Table A4: Major ingredients of the Fire Feeder ration by date (kg/tonne)

Date	Wheat	Corn DDGS	Soybean Meal	Barley	Canola Meal	Peas	Hulless Barley
8-Feb-10	443	87	25	387		20	
21-Apr-10	225	250	10	458	16		